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TECHNICAL REPORT DRP-95-1

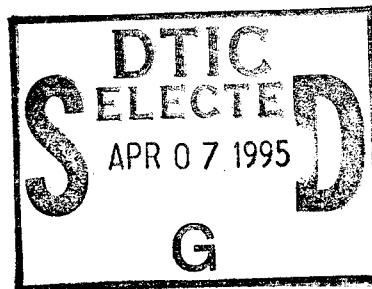
PLUME MEASUREMENT SYSTEM (PLUMES) TECHNICAL MANUAL AND DATA ANALYSIS PROCEDURES

by

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DEPARTMENT OF THE ARMY

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Final Report

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The Dredging Research Program (DRP) is a seven-year program of the U.S. Army Corps of Engineers. DRP research is managed in these five technical areas:

- Area 1 - Analysis of Dredged Material Placed in Open Water
- Area 2 - Material Properties Related to Navigation and Dredging
- Area 3 - Dredge Plant Equipment and Systems Processes
- Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems
- Area 5 - Management of Dredging Projects

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US Army Corps
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Dredging Research Program Report Summary



Plume Measurement System (PLUMES) Technical Manual and Data Analysis Procedures (TR DRP-95-1)

ISSUE: Conducting dredging and dredged material disposal operations in an environmentally sustainable manner can require addressing issues that involve the amount of sediment in suspension, as well as the depth, movement, and settling of suspended material clouds.

Acoustic instrumentation has been shown to be capable of producing near-synoptic measurements of currents and suspended sediments at dredging and disposal sites, instrumentation and data analysis procedures needed to be developed and documented.

RESEARCH: One of the primary objectives of the Dredging Research Program (DRP) work unit entitled "Measurement of Entrainment and Transport" was to develop methods, procedures, and equipment for monitoring sediment plumes associated with dredging and dredged material disposal operations in open water. The work unit developed the acoustic PLUMES MEasuring System (PLUMES) for this monitoring.

SUMMARY: This document is the main technical reference for PLUMES. It includes:

- Technical information on the overall system.
- Guidance on locating specific information in manufacturers' standard manuals.
- Technical information on special features of the system components not included in the manufacturers' manuals.
- Information on system operation and deployment procedures.
- Descriptions of the PLUMES software.
- Information on the data analysis procedures.

AVAILABILITY OF REPORT: The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number (601) 634-2355. National Technical Information Service (NTIS) numbers may be requested from WES Librarians.

To purchase a copy of this report, call NTIS at (703) 487-4780.

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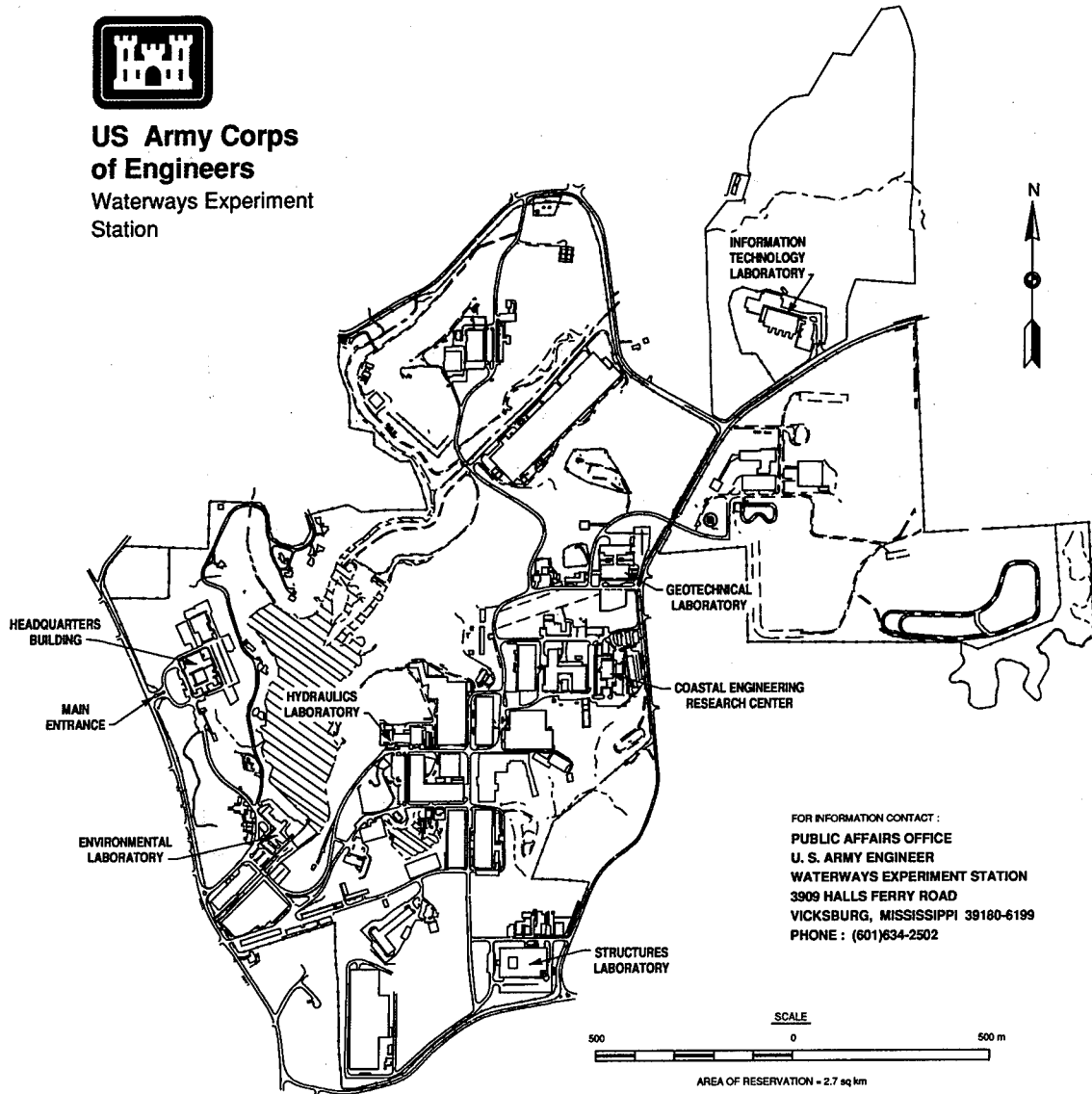
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Preface

The work described herein was authorized as part of the Dredging Research Program (DRP) by Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Work Unit 32464, "Measurement of Entrainment and Transport." The HQUSACE Chief Advisor for the DRP was Mr. Robert Campbell.

Mr. Jesse A. Pfeiffer, Jr., was HQUSACE coordinator with the Directorate of Research and Development. Messrs. Glenn R. Drummond and John H. Lockhart were HQUSACE Advisors for DRP Technical Area 1 (TA1), which included Work Unit 32464. Mr. E. Clark McNair, Jr., Coastal Engineering Research Center (CERC), U.S. Army Engineer Waterways Experiment Station, was DRP Program Manager. Dr. Lyndell Z. Hales (CERC) was the DRP Assistant Program Manager.

Dr. Billy H. Johnson, Computational Hydraulics Institute, Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station, was the Technical Manager of TA1. Work was conducted under the general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director, CERC, respectively, and Mr. Thomas W. Richardson, Chief, Engineering Development Division, CERC. Mr. Michael W. Tubman, Prototype Measurement and Analysis Branch (PMAB), CERC, was Principal Investigator of Work Unit 32464. Mr. Tubman worked under the direct supervision of Mr. William L. Preslan, Chief, PMAB.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

For further information on this report or on the Dredging Research Program, contact Mr. E. Clark McNair, Jr., Program Manager, at (601) 634-2070.

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1 Introduction

Scope

This document is the main technical reference for the **PLUme MEasurement System (PLUMES)**. It provides:

- a.* Technical information on the overall system.
- b.* Guidance on locating specific information in the standard technical manuals provided by the manufacturers of the individual system components.
- c.* Technical information on special features of the system components not included in the manufacturer's manuals.
- d.* Information on system operation and deployment procedures.
- e.* Descriptions of PLUMES software.
- f.* Information on data analysis procedures.

Overview

During dredging and dredged material disposal operations, clouds or "plumes" of suspended sediment are produced at the sites of these operations. The temporal and spacial distribution of turbidity from these plumes, and the fate of the suspended sediment in them, are important environmental concerns. PLUMES was developed to track these plumes.

The primary component of PLUMES is an RD Instruments, Inc. broad-band acoustic Doppler current profiler (BBADCP) with additional capabilities. It has five transducers on a single head (see Appendix A). The transducers on the outside are in the "Janus" configuration. Data from these transducers are used to calculate horizontal and vertical current velocities. The center transducer points straight down and measures acoustic backscatter intensities, and data from these measurements are used to track the suspended sediment

plumes. The system can be either mounted on the side of a survey boat or in an Endeco/YSI, Inc. towed vehicle and towed at depths up to 1,000 m. When used in the towed configuration, a Sea-Bird Electronics, Inc. Seacat Model SBE 16-03 Conductivity, Temperature, and Depth (CTD) recorder is mounted in the towed vehicle with the BBADCP. Integrated with the CTD is a D & A Instrument Company Optical Backscatter Sensor (OBS) Model OBS-3, that provides an independent measure of turbidity near the towed vehicle. The CTD sends its data to the BBADCP for inclusion in the data stream. An ORE International, Inc. transponder is attached to the towed vehicle. This transponder makes it possible to determine the location of the towed vehicle from onboard the towing vessel, using an ORE Trackpoint II acoustic range and bearing system. When the BBADCP is mounted on the side of the vessel, it is recommended that CTD data be collected by a separate CTD system, lowered and raised on a wire, to get a profile of the water properties. The Seacat Model SBE 16-03, described in this document, cannot be used in this profiling mode because of its relatively slow sampling rate.

The BBADCP produces current velocity measurements in a series of "bins" along each beam out to its maximum range. The maximum operational range depends on the acoustic energy loss mechanisms discussed in Chapter 2, under "Sonar Equation." The velocity transducers are mounted oriented 30 deg to the vertical, and as a result, the beams diverge away from the instrument. The BBADCP calculates horizontal and vertical current velocities from these four beams assuming that the currents are uniform over the entire region covered by the beams. When the seafloor is within about 120 percent of the BBADCP's maximum operational range, it can be detected and used to determine the velocity of the system over the bottom. This is referred to as "bottom tracking." This velocity is vectorially subtracted from the measured current velocities to give the true current velocity. If the bottom is out of range, ship position data from a navigation device (such as a Differential Global Positioning System (DGPS)) are used to determine the system's velocity for this correction. In the case of the towed configuration, the navigation device and the position data from the acoustic range and bearing system are used to determine the velocity of the system over the bottom.

The acoustic energy received by the fifth transducer is called acoustic backscatter, and its intensity depends on the number of sediment particles in the beam. Thus the intensity of the backscatter provides information on sediment concentration. Backscatter intensity also depends on the size of the particles and the specific system frequency. It decreases with decreasing particle size and decreasing frequency.

Component Technical Manuals

Standard technical manuals for the component instruments in PLUMES can be obtained from the manufacturers of those instruments, as presented in Table 1.

Table 1
Standard Technical Manuals for Component Instruments in
PLUMES

BBADCP
<i>Direct-Reading Broadband Acoustic Doppler Current Profiler Technical Manual for the Army Corps of Engineers PLUMES Project</i> , RD Instruments, Inc., 9855 Businesspark Ave., San Diego, CA 92131. Tel# 619-693-1178, FAX# 619-695-1459.
CTD
<i>Seacat SBE 16-03 Conductivity and Temperature Recorder Operating Manual</i> , Sea-Bird Electronics, Inc., 1808 - 136th Place NE, Bellevue, WA 98005. Tel# 206-643-9866, FAX# 206-643-9954.
OBS
<i>Instruction Manual, OBS - 1 & 3, Suspended Solids & Turbidity Monitor</i> , D & A Instrument Company, 40 - A Seton Road, Port Townsend, WA 98368. Tel# 206-385-0272, FAX# 206-385-0460.
Towed Vehicle
<i>CPV - Fin Technical Bulletin</i> , Endeco/YSI, Inc., 13 Atlantis Dr., Marion, MA 02738-1448. Tel# 508-748-0366, FAX# 508-748-2543.
Acoustic Tracking System
<i>Operation and Maintenance Manual for the ORE International, Inc. Model 4410C Trackpoint II System and Operation and Maintenance Manual for the ORE International, Inc. Model 4330A Multibeacon</i> , ORE International, Inc., Box 709, Falmouth Heights Road, Falmouth, MA 02541. Tel# 508-548-5800, FAX# 508-540-3835.

2 Methodology

Current Measurements

The BBADCP transmits 600- or 1,200-kHz (depending on the system) acoustic pulses simultaneously from the transducers on the outside of the central transducer. These are transmitted along beams oriented at 30 deg from the vertical. Sound is returned to the transducers from along the beams. This returned sound is the backscatter from small particles, such as suspended sediment and zooplankton, drifting ambiently with the currents. During each transmission, the BBADCP sends out two or more pulses separated by a time difference called a lag. The compression or expansion of this lag in the returned signal depends on the velocity of the scatterers along the beam. The lags will be compressed if the scatterers are moving toward the transducers, and expanded if they are moving away from the transducers. A detailed description of how the signals are processed to produce velocity measurements along the beams is given in the first chapter of the RDI manual.

The three components of horizontal and vertical velocities (x, y, and z) are calculated from the four beam velocities. Because three beam velocities are sufficient to calculate the x, y, and z velocities, the data from a beam whose quality falls below a specified limit can be excluded from the calculations. Data are processed in depth cells along the beam, perpendicular to the vertical axis. There can be up to 128 of these cells. Current speed and direction calculated for each cell thus represent the current in a horizontal slab of water, assumed to be uniform across the entire horizontal distance spanned by all four (or possibly three) beams.

Acoustic Backscatter Intensity Measurements

Sediment suspended in the water along the central fifth beam backscatters sound which is received by the transducer. The intensity of this backscatter can be used to theoretically calculate the concentrations of the suspended sediment along the beam. The relationship between suspended sediment concentration and acoustic backscatter intensity measured by a BBADCP has been established in a laboratory test tank (Lohrmann and Huhta 1994). In the field,

where conditions vary rapidly, the vertical range of measurements is much greater than what existed in the laboratory, and clay and silt particles are present that have shapes significantly different than the nearly spherical particles used in the laboratory calibration, determination of sediment concentration from acoustic backscatter intensity is still experimental. The theory behind the relationship is presented in this section.

Rayleigh Scattering

At 600 and 1,200 kHz, the acoustic wavelength is greater than the size of the suspended sediment particles present at most dredging operation sites. As the wave passes through the water, it causes the particles to move back and forth; however, their motion lags behind the wave. This lagging oscillation reradiates acoustic energy in all directions, some of which goes back toward the source. Intensity of the backscatter depends on the number of sediment particles in the beam. Thus the intensity of the backscatter provides a measure of sediment concentration. This phenomenon is known as "Rayleigh scattering." The validity of Rayleigh scattering theory for suspended sediment with grain-size radii much smaller than the acoustic wavelengths of the sensing systems has been shown by Hay and Sheng (1992) and Thorne et al. (1993). Lohrmann and Huhta (1994) have shown that for a 600-kHz PLUMES system, the backscatter from suspended particles in a laboratory calibration chamber agrees well with a Rayleigh scattering model for sediments with grain sizes from approximately 30 to 800 microns (diameter). For a special 2-MHz system, they found good agreement with Rayleigh scattering for particles from approximately 30 to 120 microns.

Rayleigh's model predicts that the backscatter for spheres much smaller than the wavelength is proportional to the volume concentration, the fourth power of the frequency and the third power of the sphere's radius. The volume backscattering strength S_v from Rayleigh scattering for spheres, is the spherical-wave intensity (i.e., energy flux per unit solid angle) in the backward direction scattered from a unit volume of water insonified by a plane wave of unit intensity, converted to dB. In units of dB re 1/m/steradian, it can be expressed in a form similar to Ogushwitz (1994) as follows:

$$S_v = 10\log_{10}(C_v k^4 a^3) + 10\log_{10}(k_1) + 20.0 \quad (1)$$

where

C_v = volume concentration of scatters (cm^3/cm^3)

k = wave number (cm^{-1} i.e., $2\pi/\text{wavelength}$)

a = particle radius (cm)

k_1 = constant

In reality, there is not a single particle size, but a distribution of sizes, and the data processing software performs the calculations using a discrete number of particle size classes, weighted in Equation 1 according to the percent of material in each class.

The constant k_1 is a function of the relative density and elasticity of the spheres and is given by the following (see Clay and Medwin (1977)):

$$k_1 = \frac{3}{4}\pi\left(\frac{e-1}{3e} + \frac{g-1}{2g+1}\right)^2 \quad (2)$$

where

e = ratio of particle/water elasticity

g = ratio of particle/water density

Sonar Equation

The sonar equation for PLUMES assumes that the quantity and size distribution of suspended sediment particles are continuous and uniform for any cross section perpendicular to the axis of the acoustic beam. The equation relates the equivalent plane-wave reverberation level RL to the PLUMES acoustic source level SL , the total acoustic loss AL , the volume backscattering strength (given by Equation 1) of the suspended sediment, and the reverberation volume RV , as follows:

$$RL = SL - AL + S_v - RV \quad (3)$$

where

RL = equivalent plane-wave reverberation level (dB re 1 micro Pa)

SL = source level (dB re 1 micro Pa at 1 m)

AL = total acoustic loss (dB re 1 m)

RV = reverberation volume (dB re 1/m)

The acoustic-loss term AL in Equation 3, is composed of terms representing four acoustic attenuation mechanisms. They are geometric spreading LS , absorption α_w , and combined viscous attenuation and scattering α_{vs} . These terms compose AL as follows:

$$AL = 2\alpha_w r + \alpha_{vs} r + LS \quad (4)$$

where

α_w = absorption coefficient (dB/m)

r = distance along beam (m)

α_{vs} = two-way viscous attenuation and scattering geometric spreading loss (dB)

LS = one-way geometric spreading loss (dB)

The first loss mechanism, geometric spreading, is a result of the acoustic wave front expanding along its wave path, and the acoustic energy per unit area decreasing with distance. The spreading loss is independent of frequency. The one-way spreading loss α_s , in dB, is given for the "far field" by the following (see Clay and Medwin (1977)):

$$LS = 20\log_{10}(r) \quad (5)$$

The far field for a 600-kHz BBADCP is approximately any distance greater than 4 m. For a 1,200-kHz system, the near field is less than the system's recommended blanking distance (see Appendix E).

The second loss mechanism is absorption of energy by the water; this effect increases with increasing frequency. The absorption coefficient α_w , in dB per meter, is given by (see Stephens (1970)):

$$\alpha_w = 8.686 \left[\frac{2.34 \times 10^{-9} S f^2}{(1 + f^2 f_T^2) f_T} + \frac{3.38 \times 10^{-9} f^2}{f_T} \right] (1 - 62.46 P_s) \quad (6)$$

where

f = frequency (Hz)

S = salinity (ppt)

P_s = pressure (Pa)

f_T = relaxation frequency = $21.9 \times 10^{(9 - \frac{1520}{T+273.15})}$

where

T = temperature (°C)

The third loss mechanism is viscous attenuation. The lagging oscillations of the sediment particles in the beam cause shear forces that result in an energy loss due to the viscosity of the water. This viscous effect depends on the shape of the particles and increases with increasing frequency and increasing concentration. The fourth loss mechanism is scattering, caused by scattering of acoustic energy in directions out of the beam. Combined two-way viscous attenuation and scattering losses α_{vs} , in dB per meter, are given as follows by Urick (1948) (as corrected by Blue and McLeroy (1968)):

$$\alpha_{vs} = 434.1 \times 10^{-4} C_v [k(g-1)^2 \frac{u}{u^2 + (g+w)^2} + \frac{k^4 a^3}{3}] \quad (7)$$

where

$$B = \left(\frac{\omega}{2\nu}\right)^{1/2}, \quad u = \frac{9}{4Ba} \left(1 + \frac{1}{Ba}\right)$$

$$g = \frac{\rho_1}{\rho_0}, \quad w = \frac{1}{2} + \frac{9}{4Ba}$$

$$\omega = 2\pi f \text{ where } f \text{ is frequency (Hz)}$$

$$\nu = \text{kinematic viscosity (cm}^2\text{ s}^{-1}\text{)}$$

$$\rho_1 = \text{particle density}$$

$$\rho_0 = \text{water density}$$

As is the case with Equation 1, in the data processing software, calculations using Equation 7 are performed using a discrete number of size classes to represent a grain-size distribution.

AL , as expressed in Equation 4, would be equivalent to the two-way transmission loss in an active sonar (Urick 1983), except for the fact that the spreading-loss term is one-way and not doubled for the transmitted and return signal. This is accounted for in the way the reverberation volume RV is defined, and is a consequence of the assumed uniform distribution of scatterers across the beam. Also, Equation 4 is written as it would appear if the parameters contributing to the absorption and viscous attenuation and scattering losses were uniform along the beam (i.e., along r). This usually isn't true, and AL is numerically integrated along r in the data processing software.

The reverberation volume for the 600-kHz PLUMES, in dB re 1/m, is given as follows:

$$RV = 7.62 + 20 \log_{10} (1/ka_r) - 10 \log_{10} (L_p) \quad (8)$$

where

a_t = effective transducer radius (cm)

L_p = effective pulse length (m)

The effective radius is based on the -3-dB beam width. The effective radius of the fifth beam's transducer for the 600-kHz system is 5.15 cm, and for the 1,200-kHz system it is 2.55 cm. The effective pulse length L_p is described in the next section.

Transmitted Signals

Transmitted signals for the 600- and 1,200-kHz systems are actually 614.4 and 1,228.8 kHz, respectively. These values should be used for all equations with a frequency term. The transmitted signal for the fifth beam is different from that transmitted by the other four transducers for the water velocity measurements. The signal transmitted by the fifth beam is one or more repetitions of a 17-element biphasic coded pulse. These are repeated at 19-element intervals (i.e., there is a two-element gap), as many times as needed to match the depth cell length. The length of each code element is approximately 4.88 mm for the 600-kHz system. The phase of the transmitted signal is changed by 180 deg at the end of a code element whenever the code changes. The length of each code element (i.e., .00488 m), times the number of code elements (i.e., 17), times the number of code repeats that it takes to fill a depth cell is the effective pulse length L_p . With the 2-element gap, each 17-element code has a length of 0.0928 m, so the number of code repeats that it takes to fill a cell is the truncation to the next lowest integer of the depth cell length divided by 0.0928 m. The fifth-beam pings occur between velocity pings.

The acoustic power radiated by the fifth transducer when transmitting, and the characteristics of the transducer, determine the source level SL in dB re 1 micro Pa at 1m, for the sonar equation (Equation 3). It can be expressed as follows in a form that includes terms that need to be determined by a laboratory acoustic calibration of the system. That is:

$$SL = 20 \log_{10} (VDC) + Cal_1 + Cal_2 T \quad (9)$$

where

VDC = the system voltage level recorded with the data (volts)

Cal_1 = the first calibration value (dB)

Cal_2 = the second calibration value (dB/°C)

Received Signal Processing

The signal received from the fifth beam transducer passes through passive tuning elements on the vertical beam tuning board and is amplified approximately 20 dB by the linear preamplifier on the third receiver board (see Appendix B). It then goes to a logarithmic amplifier. The bandwidth of the transducer and amplifier is 40 percent of the carrier frequency, while the bandwidth of the signal itself is 25 percent. The rectified output of the logarithmic amplifier is filtered to meet the Nyquist criterion for a sampling rate of 38.4 kHz. Sampling is done with an 8-bit analog-to-digital converter (ADC) on the third demodulator board (see Appendix B). The sampling rate is equivalent to about one sample every 2 cm for a 600-kHz system. The samples within each depth cell are averaged together and placed in the ensemble record as fifth beam intensity in units of ADC counts. Each count represents about 0.406 dB of received signal power. The reverberation level RL , in dB, for the sonar equation (Equation 3), can be expressed in terms of the ADC counts and terms that need to be determined by a laboratory acoustic calibration of the system as follows:

$$RL = Cal_3 C_{ADC} + Cal_4 + Cal_5 T \quad (10)$$

where

C_{ADC} = ADC counts

Cal_3 = third calibration value (dB/count)

Cal_4 = fourth calibration value (dB)

Cal_5 = fifth calibration value (dB/°C)

Since the logarithmic measurement is linearly averaged over each depth cell, the average reverberation level in the depth cell will be biased slightly low if an abrupt change of suspended sediment concentration occurs within the depth cell. The accuracy of the measurement of acoustic backscatter intensity by this system is no better than ± 2 dB. According to Equation 3, this means that the accuracy of concentrations determined from the measurements can be no better than ± 50 percent.

As given by Equation 10, RL is not exactly the same as the reverberation level in the sonar equation (Equation 3), because the received signal given in ADC counts includes the system and thermal noise. The data processing software subtracts the system and thermal noise, and the background (i.e., the acoustic intensity recorded when no suspended sediment from dredged material is present in the beam). This is done in linear (i.e., not log), space and the system and thermal noise are very small corrections, except near maximum range.

Grain-Size Distribution

The fact that the acoustic backscatter for Rayleigh scattering is a function of the third power of the size of the suspended sediment grains, as shown by Equation 1, has significant implications for applying the theory to field data. Because of the third power dependence on particle size, the amount of fine material in a plume with a realistic grain-size distribution does not significantly affect the calculations of concentration from backscatter data according to Rayleigh theory. For example, if 45 percent of the material in a plume had a 0.5-micron radius, it would contribute to the backscatter intensity about as much as 0.01 percent of the material would with a grain size of 9.5 microns. On the other hand, calculated results depend greatly on the amount of large-grain sediment in the plume and small changes in the distribution for the larger particles cause very large changes in the calculated concentrations.

Grain-size distribution in a plume will change with time, since the sediment particles fall out of suspension at a rate which depends on their grain sizes. Larger particles fall at a faster rate than do smaller particles. The change in the grain-size distributions with time can be predicted using fall velocities determined from equations given in Chapter 4 of the *Shore Protection Manual* (1984) for grain sizes greater than 31 microns. For grain sizes less than 31 microns, the fall velocities are so small that over the time spans that are generally practical for tracking plumes (i.e., less than approximately 6 hr), the distributions below 31 microns do not vary much with time. Fall velocity V_f , in centimeters per second, is given by the *Shore Protection Manual* as follows:

$$V_f = \frac{(\rho_1 - \rho_0)4a^2G}{18\eta\rho_0} \quad (11)$$

where

G = gravitational acceleration (centimeters per square second)

Given an initial concentration, or the concentration at certain times in a plume being tracked, Equation 11 can be used to calculate the distribution at all times of interest. How accurately this can be done and how it affects the accuracy of the concentration calculations is a subject of current research by several investigators.

Water Property Measurements

For processing PLUMES data, the physical properties of the water that need to be determined from measurements are: depth of the system, temperature and salinity of the water, its density, and sound speed. The Seacat CTD, which is mounted on the towed vehicle for PLUMES, measures pressure, conductivity, and temperature, as would a separate CTD system used when the

BBADCP is mounted on the side of a boat. All other properties are calculated using these measurements. The Seacat has a two-electrode conductive sensor to measure the conductivity in a volume of seawater flowing through a glass tube. Temperature is measured with a pressure-protected thermistor, and a strain-gauge pressure sensor measures the pressure. The Seacat uses a Wein-bridge oscillator interface technique for conductivity and temperature sensors, and output for these measurements is frequency. Output of the pressure sensor is voltage. The instrument samples these sensors every 15 sec, and transfers the data to the BBADCP, where it is incorporated into its data record. Using the equations and calibration coefficients (see Appendix C) for the sensors provided by Sea-Bird, conductivity frequency is converted to conductivity C , in milli mho (mmho)/cm, temperature frequency is converted to temperature T , in degrees Celsius, and pressure voltage in counts is converted to pressure P , in decibars (dbar). The pressure exerted by a 1-m column of seawater is approximately 1 dbar and pressure in dbar is used in this document interchangeably with depth in meters.

Salinity

Salinity S in parts per thousand (ppt) is calculated using the 1978 practical salinity scale equations (Lewis 1980). The conductivity ratio R is the ratio between the conductivity of the measured seawater, $C(S,T,P)$ to that of seawater at 35 ppt, 15 °C, and 0 pressure, $C(35,15,0)$. For analyzing the Seacat data this is 42.914 mmho/cm. Thus:

$$R = \frac{C(S,T,P)}{42.914} \quad (12)$$

The ratio r_T is:

$$r_T = c_0 + c_1 T + c_2 T^2 + c_3 T^3 + c_4 T^4 \quad (13)$$

where

$$c_0 = 6.766097 \times 10^{-1}$$

$$c_1 = 2.00564 \times 10^{-2}$$

$$c_2 = 1.104259 \times 10^{-4}$$

$$c_3 = -6.9698 \times 10^{-7}$$

$$c_4 = 1.0031 \times 10^{-9}$$

The ratio R_P is:

$$R_P = 1 + \frac{(A_1 + A_2P + A_3P^2)P}{1 + B_1T + B_2T^2 + B_3R + B_4RT} \quad (14)$$

where

$$\begin{aligned} A_1 &= 2.070 \times 10^{-5} \\ A_2 &= -6.370 \times 10^{-10} \\ A_3 &= 3.989 \times 10^{-15} \\ B_1 &= 3.426 \times 10^{-2} \\ B_2 &= 4.464 \times 10^{-4} \\ B_3 &= 4.215 \times 10^{-1} \\ B_4 &= -3.107 \times 10^{-3} \end{aligned}$$

The ratio R_T is:

$$R_T = \frac{R}{R_P r_T} \quad (15)$$

Finally, the salinity S in parts per thousand, is:

$$S = \sum_{j=0}^5 a_j R_T^{\frac{j}{2}} + \frac{(T - 15)}{1 + m(T - 15)} \sum_{j=0}^5 b_j R_T^{\frac{j}{2}} \quad (16)$$

where

$$\begin{aligned} m &= 0.0162 \\ a_0 &= 0.0080 & b_0 &= 0.0005 \\ a_1 &= -0.1692 & b_1 &= -0.0056 \\ a_2 &= 25.3851 & b_2 &= -0.0066 \\ a_3 &= 14.0941 & b_3 &= -0.0375 \\ a_4 &= -7.0261 & b_4 &= 0.0636 \\ a_5 &= 2.7081 & b_5 &= -0.0144 \end{aligned}$$

Density

Density of seawater ρ_w , in kilograms per cubic meter, is calculated using Equations 17 through 26 (see Millero et al. (1980) and Millero and Poisson (1981)). The secant bulk modulus of pure water K_w is:

$$K_w = e_0 + e_1 T + e_2 T^2 + e_3 T^3 + e_4 T^4 \quad (17)$$

where

$$\begin{aligned} e_0 &= -1930.06 & e_2 &= -2.327105 \\ e_1 &= 148.4206 & e_3 &= 1.360477 \times 10^{-2} \\ e_4 &= -5.155288 \times 10^{-5} \end{aligned}$$

The secant bulk modulus of seawater at 0 pressure, $K(S,T,0)$, is:

$$\begin{aligned} K(S,T,0) &= K_w + (f_0 + f_1 T + f_2 T^2 + f_3 T^3)S \\ &\quad + (g_0 + g_1 T + g_2 T^2)S^{\frac{3}{2}} \end{aligned} \quad (18)$$

where

$$\begin{aligned} f_0 &= 54.6746 & g_0 &= 7.944 \times 10^{-2} \\ f_1 &= -0.603459 & g_1 &= 1.6483 \times 10^{-2} \\ f_2 &= 1.09987 \times 10^{-2} & g_2 &= -5.3009 \times 10^{-4} \\ f_3 &= -6.670 \times 10^{-5} \end{aligned}$$

The pressure coefficient A_w is:

$$A_w = h_0 + h_1 T + h_2 T^2 + h_3 T^3 \quad (19)$$

where

$$\begin{aligned} h_0 &= -0.1194975 \\ h_1 &= 1.43713 \times 10^{-3} \\ h_2 &= 1.16092 \times 10^{-4} \\ h_3 &= -5.77905 \times 10^{-7} \end{aligned}$$

The pressure coefficient B_w is:

$$B_w = l_0 + l_1 T + l_2 T^2 \quad (20)$$

where

$$\begin{aligned} l_0 &= 3.47718 \times 10^{-5} \\ l_1 &= -6.12293 \times 10^{-6} \\ l_2 &= 5.2787 \times 10^{-8} \end{aligned}$$

The pressure coefficient A is:

$$A = A_w + (i_0 + i_1 T + i_2 T^2)S + j_0 S^{\frac{3}{2}} \quad (21)$$

where

$$\begin{aligned} i_0 &= 2.2838 \times 10^{-3} \\ i_1 &= -1.0981 \times 10^{-5} \\ i_2 &= -1.6078 \times 10^{-6} \\ j_0 &= 1.91075 \times 10^{-4} \end{aligned}$$

The pressure coefficient B is:

$$B = B_w + (m_0 + m_1 T + m_2 T^2)S \quad (22)$$

where

$$\begin{aligned} m_0 &= -9.9348 \times 10^{-7} \\ m_1 &= 2.0816 \times 10^{-8} \\ m_2 &= 9.1697 \times 10^{-10} \end{aligned}$$

The secant bulk modulus of seawater $K(S,T,P)$ is:

$$K(S,T,P) = K(S,T,0) + AP + BP^2 \quad (23)$$

The density of pure water ρ_w is:

$$\rho_w = J_0 + J_1 T + J_2 T^2 + J_3 T^3 + J_4 T^4 + J_5 T^5 \quad (24)$$

where

$$\begin{aligned} J_0 &= -28.263737 \\ J_1 &= 6.793952 \times 10^{-2} \\ J_2 &= -9.095290 \times 10^{-3} \\ J_3 &= 1.001685 \times 10^{-4} \\ J_4 &= -1.120083 \times 10^{-6} \\ J_5 &= 6.536332 \times 10^{-9} \end{aligned}$$

The density of the seawater at 0 pressure $\rho(S,T,0)$ is:

$$\rho(S,T,0) = \rho_w + (K_0 + K_1T + K_2T^2 + K_3T^3 + K_4T^4)S \quad (25)$$

$$+ (k_0 + k_1T + k_2T^2)S^{\frac{3}{2}} + X_0S^2$$

where

$$\begin{aligned} K_0 &= 8.24493 \times 10^{-1} & k_0 &= -5.72466 \times 10^{-3} \\ K_1 &= -4.0899 \times 10^{-3} & k_1 &= 1.0227 \times 10^{-4} \\ K_2 &= 7.6438 \times 10^{-5} & k_2 &= -1.6546 \times 10^{-6} \\ K_3 &= -8.2467 \times 10^{-7} \\ K_4 &= 5.3875 \times 10^{-9} & X_0 &= 4.8314 \times 10^{-4} \end{aligned}$$

Finally, the density of seawater $\rho(S,T,P)$, in kilograms per cubic meter, is:

$$\rho(S,T,P) = \rho(S,T,0)/[1 - P/K(S,T,P)] \quad (26)$$

Sound Speed

Due to the fact that the system is working over relatively short distances, a fairly simple equation for the sound speed in seawater gives sufficiently accurate results. The one used for analyzing PLUMES data is from Clay and Medwin (1977). It can be written as follows, where C_s is in units of meters per second.

$$\begin{aligned} C_s &= 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 \\ &+ (1.34 - 0.010T)(S - 35) + 0.016P \end{aligned} \quad (27)$$

Optical Turbidity Measurements

The OBS uses an optical sensor to measure turbidity and suspended solids concentrations by measuring infrared (IR) radiation backscattered from suspended matter. As with acoustic backscatter, the IR backscatter changes with changing particle size and changes depending on the composition and shape of the suspended particles. However, unlike the acoustic sensor, the OBS is insensitive to bubbles and organic matter.

The OBS has an infrared emitting diode, four photo diodes to detect backscatter, and a linear, solid-state temperature transducer to correct the

measurements for temperature effects. The beam width (defined by the half-power points), is 50 deg along the instrument's major axis, and 30 deg perpendicular to it. The volume sampled by OBS depends on how far the IR beam penetrates into the water. This volume decreases as sediment concentration increases, but the range is roughly 2 to 5 cm in front of the sensor. Visible light incident on the sensor is absorbed by a filter. The output of the OBS is a voltage from 0 to 5 V. The OBS is connected to the CTD, which provides its power and receives its output voltage. The CTD processes the signal through an analog-to-digital convertor and includes the value in the data it sends to the BBADCP.

The relationship between OBS readings and concentrations can be established by laboratory calibration of the system. The calibration procedure can be found in the OBS manual. For the calibration, actual dredged material should be used, preferably from water samples including the suspended material, but a representative sample of the material taken prior to disposal may be adequate. The relationship between concentration and output voltage is nearly linear up to a point, as long as the grain-size distribution and composition remain the same as those used for the calibration. However, these do not remain constant over the typical monitoring period for a dredged-material disposal operation. The primary function of the OBS in PLUMES is to determine if the measured acoustic backscatter is from suspended sediment, which also produces IR backscatter, or from organic matter, which produces acoustic backscatter, but not IR backscatter.

Positioning

Very accurate positioning (i.e. navigation) of the system during monitoring is important for two reasons. The first is that the system's speed over the bottom must be determined and vectorially subtracted from the system's current measurements to get water velocities. Separate positioning information is not needed to perform this function when the monitoring system can track bottom. The second is that the navigation data can be used during post-processing to display the plumes with their correct dimensions. Plumes can maintain their shape over limited depth ranges during monitoring, and their dimensionally correct appearance can be a good way to identify them as they are repeatedly acquired and measured during monitoring. The PLUMES data acquisition software (DAS) accommodates navigation input and will record the position data with the PLUMES data. Navigation using a DGPS is recommended for PLUMES monitoring.

Deepwater monitoring of dredged-material disposal requires that PLUMES be mounted in a towed vehicle and towed at depth. In this configuration, it is necessary to determine not only the position of the ship, but also the position of the towed vehicle relative to the ship. This is accomplished by attaching a transponder to the towed vehicle and measuring its range and bearing using an acoustic system on the ship. The shipboard system generates an acoustic interrogation signal of either 17 or 19 kHz. When the transponder detects the

signal, it replies with an acoustic signal between the frequencies of 22 and 30 kHz. This signal is received by the shipboard system, which then calculates the distance to the transponder using a representative sound speed, the total time between when it sent the interrogation signal and when it received the reply signal, and the known signal turnaround time of the transponder.

The shipboard system is an ultrashort baseline acoustic tracking system. It uses a phased-array hydrophone composed of transducers arranged at the vertices of an equilateral triangle. The separation between the elements in the array is less than one wavelength. When the acoustic wave hits the array, it is received by the individual transducers in the array in an order which depends on the angle of the wave relative to the array geometry. Phase differences between the measurements of the wave at each transducer provide the information required to calculate the wave's direction of propagation relative to the array. This direction can be described in terms of a bearing and depression angle. The bearing of the transponder is measured in degrees relative to the hydrophone heading. The depression angle is formed by the intersection of a horizontal plane with the hydrophone and a line drawn from the hydrophone to the towed vehicle. The most accurate measurements of these angles are made when the transponder is within a 45-deg angle from the vertical axis of the hydrophone (i.e. the depression angle is between 45 deg and 90 deg).

The system produces both a visual representation of the towed vehicle position and an RS232 output of this information. Position data are sent to the navigation computer, which combines them with the DGPS data to determine the geographic position of PLUMES. This position data can be sent to DAS to be recorded with the PLUMES data (see Appendix F for the required format).

3 Deployment Procedures

PLUMES can be configured for two types of operations. One is for shallow water (i.e., less than 60 m for a 600-kHz system), where it is rigidly mounted on the side of a small boat. The other is for deep water, where it is mounted in a towed vehicle and towed at depth.

Shallow-Water Configuration

The shallow-water configuration is shown in Figure 1. In shallow water, the water properties and optical-turbidity measurements become a separate operation, for which the boat is stopped and the CTD system with the integrated OBS sensor is lowered to the bottom to get a profile. This requires a profiling CTD, and cannot be done with the SBE 16-03 used in the deepwater configuration.

Setup

To prepare PLUMES for shallow-water operations, the procedures given below are used. Figure 1 and Appendix A are used for parts identification.

- a.* The RDI BBADCP must be in the in-line configuration for shallow-water operations so it can be placed in a mounting system attached to the boat. If the transducer-head assembly is installed using the 90-deg elbow, the procedures found in Section 4-4 of the RDI Manual are followed to convert the BBADCP to the in-line configuration.
- b.* Place the aluminum mounting system over the gunnel of the boat. Screw a wooden pad to the inside of the plate that is on the outside of the boat. The width of the pad should be such that, with the outside edge of the gunnel hard against the plate, the wood fills any gap that exists between the plate and the side of the boat below the gunnel.
- c.* Screw the two clamps on the inside of the boat tight against the side of the boat to hold the system in place.

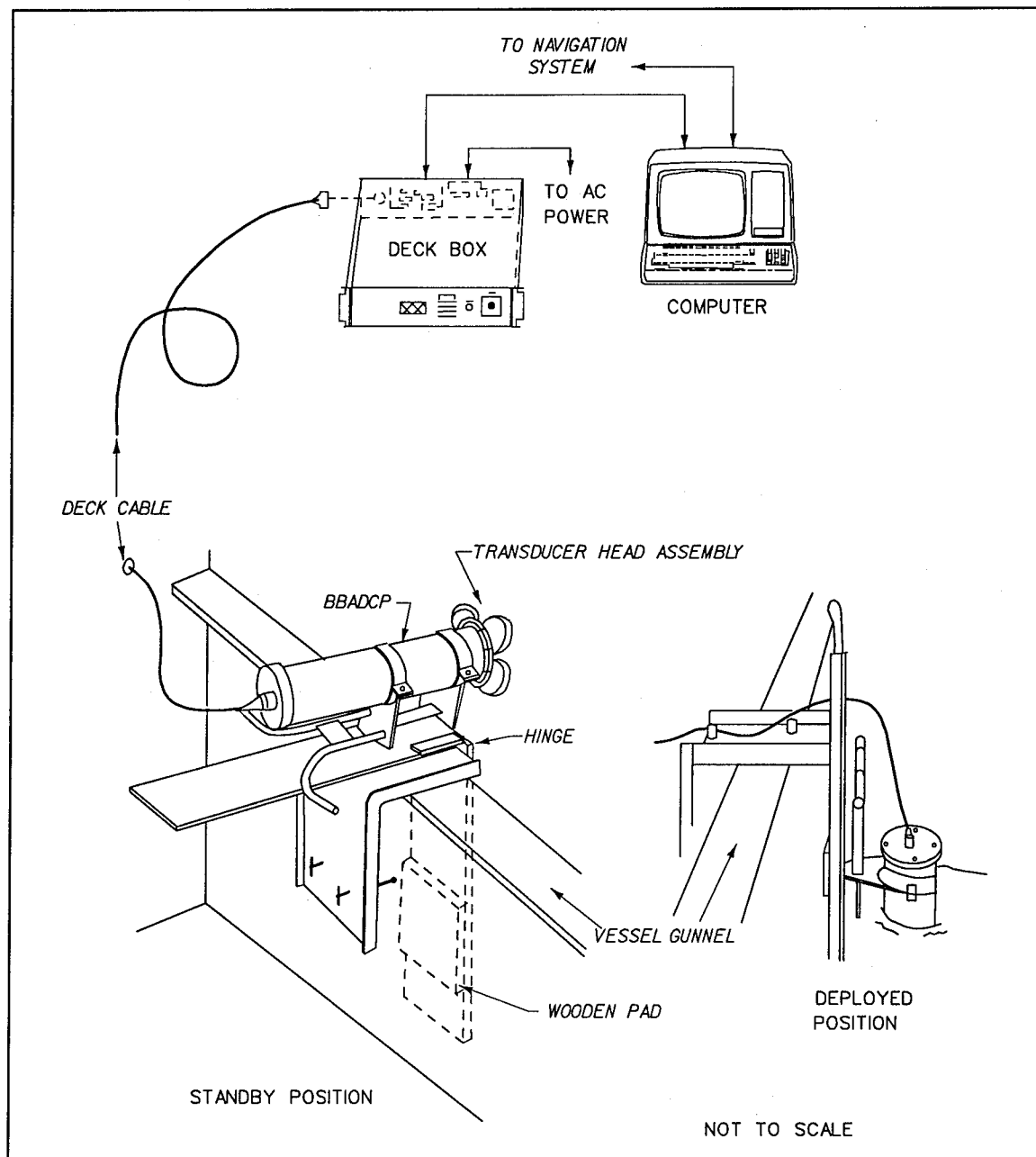


Figure 1. Shallow-water configuration

- d. Remove the top pieces of the mounting clamps for the BBADCP and place the BBADCP on the bottom pieces with the transducer head assembly facing out, and the beam 3/beam 4 axis parallel to the ship with beam 3 forward (beam numbers are stamped on the transducer housings). In the standby position, the BBADCP should be placed on the mounting clamps, with its weight centered over the gunnel. Place the top pieces over the BBADCP and install the retaining bolts. Place the washers and lock washers on the bolts and fasten the nuts. The

nuts should be screwed down firmly, but not made completely tight until deployment.

- e.* Screw the waterproof connector at one end of the deck cable to the inboard (top) end of the BBADCP. Screw the other end to the connector (labeled "ADCP") on the back panel of the deck box labeled "ADCP." The ADCP connector is the one farthest to the right as you face the rear panel (see Appendix A).
- f.* Plug the female end of the deck-box power cable to the plug on the back panel labeled "INPUT, 98-264 VAC." The power connector is the one farthest to the left as you face the rear panel (see Appendix A).
- g.* Connect one end of the RS232 cable to the connector on the back panel of the deck box labeled "CHANNEL 1, RS232(J20)." The Channel 1 RS232 connector is at the center of the back panel (see page A-4 in the RDI Manual). Connect the other end of the RS232 cable to serial port 1 on the computer.
- h.* Connect the navigation device output to serial port 2 on the computer.
- i.* System operating parameters for the BBADCP firmware and the data acquisition software (DAS) are described in Chapter 4.

Deployment

To deploy the shallow-water configuration of PLUMES, follow the procedures given below. Figure 1 and Appendix A provide parts identification.

- a.* Turn the power switch on the front panel of the deck unit clockwise to the "on" position. Push the reset button. The green LED data lights on the front panel will begin to blink within 10 sec, indicating that data are being received from the BBADCP.
- b.* Start DAS and observe data being displayed and stored as described in Chapter 4.
- c.* Loosen the clamps around the BBADCP and slide it outboard until the inboard clamp is nearly at the top of the BBADCP pressure housing. Tighten the nuts on the clamps.
- d.* Tilt up the plate with the BBADCP attached until the BBADCP is vertical.
- e.* Slide the plate down into the retaining slots on the outboard plate and lower the instrument into the water. Use the curved round bars for holding onto the instrument as it is lowered.

- f. When the BBADCP transducer head assembly is below the boat's keel, insert the two locking pins (not shown) to lock the sliding plate in place.

Deepwater Configuration

The deepwater configuration is shown in Figure 2. In deep water, the range of the system is less than the depth of the water, and it is necessary to profile several vertical sections of the water column to cover the total depth. To accomplish this, PLUMES is mounted in a towed vehicle and towed at depths up to 1,000 m. In this configuration, data are transmitted over a seven-conductor electro-mechanical tow cable, which has haired faring on it for approximately 20 percent of its length immediately above the towed vehicle. To tow the system at a depth of 1,000 m, the tow cable must be approximately 3,000 m long (see Appendix D for dimensions and tow characteristics of the towed vehicle). The towed body is manufactured by Endeco/YSI in Marion, MA. It is of fiberglass construction in a dihedral-winged, passive depressor design. The manufacturer claims that the vehicle can accommodate tow speeds from 2 to 12 knots with stable roll and pitch characteristics. The manufacturer specifies the maximum roll to be ± 2 deg and the maximum pitch to be ± 3 deg at 10 knots.

Setup

To prepare PLUMES for deepwater operations, follow the procedures given below. Figure 2 and Appendix A provide parts identification.

- a. The RDI BBADCP must be in the right-angle configuration for deep-water operations so it can be mounted in the towed vehicle. This requires that a 90-deg elbow be installed. If the instrument is in the in-line configuration, follow the procedures found in Section 4-4 of the RDI Manual to install the 90-deg elbow.
- b. Remove the bolt from the clevis and place it over the towed vehicle attachment eyelet with the flattened extension toward the tail of the vehicle. Insert the bolt. Put the nut on the bolt and tighten until finger tight. Put the cotter pin through the hole on the end of the bolt and bend the ends back.
- c. Put the rubber-jacketed connector lead under the small clamp behind the attachment eyelet and fasten the clamp down by installing the screws on each side of the clamp.
- d. Put the remaining cable and connector through the cut-out section of the towed vehicle and turn the vehicle over so that the hole in the bottom of it is facing up. Open clamps on all the mounting brackets.

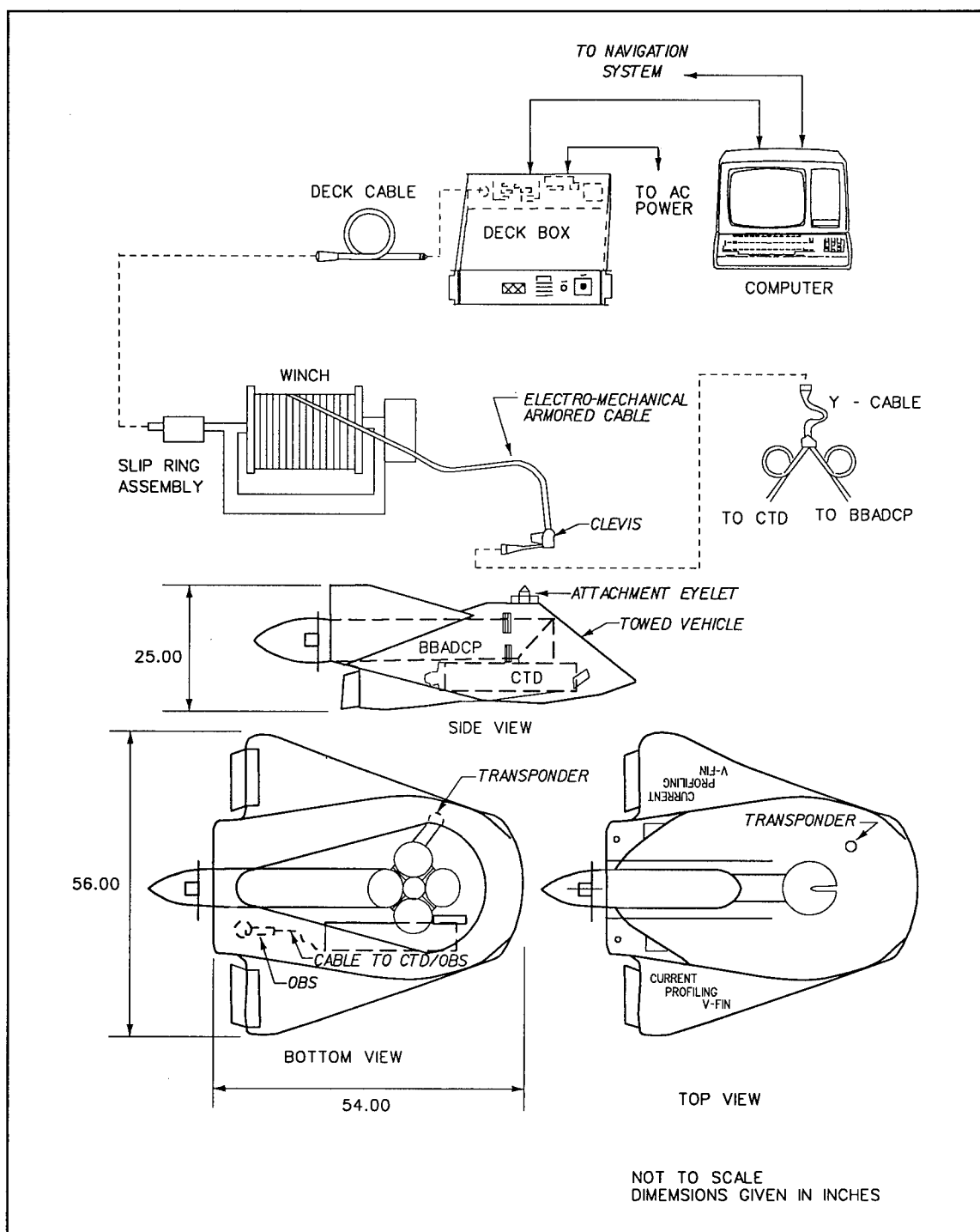


Figure 2. Deepwater configuration

- e. If the standard Seabird delrin bracket is installed on the end of the CTD opposite to the one having the connectors for the cables, it must be removed so that it will fit in the towed vehicle. Remove it by removing the two bolts which attach it to the end cap.

- f.* Apply a small amount of silicon insulating compound (e.g., Dow Corning 4 or 5 Compound) to the outside of the plastic mating surfaces on the two male connectors on the end cap of the CTD.
- g.* Plug the Y-cable's 6-pin female connector onto its mating connector on the CTD, and screw down the locking sleeve.
- h.* Plug the CTD to OBS interconnect cable's 4-pin female connector (this connector is not made of molded plastic), onto its mating connector on the CTD, and screw down the locking sleeve.
- i.* Place the CTD on its mounting blocks inside the towed vehicle, oriented so that the end with the connectors is toward the tail-end. Place the hose clamps around the CTD and tighten them.
- j.* Connect the 20-pin connector on the end of the tow cable with its mate on the Y-cable and screw the locking ring tight. Lay the Y-joint of the Y-cable inside the towed vehicle at some location out of the way of where the BBADCP will go, and run the end of it that goes to the BBADCP (i.e., the end with the 20-pin female connector) out through the cut-out section. Place it so that the cable is located as far forward as possible where it passes through the opening.
- k.* Place the BBADCP in the towed vehicle by putting the connector end through the cut-out section and putting the end of the pressure housing near the transducer head assembly on the BBADCP mounting bracket. This requires that it be guided through the opening with the axis of the BBADCP at about a 30-deg angle to the longitudinal center axis of the towed vehicle.
- l.* Put on the top clamp of the BBADCP mount. Put the washers, lock washers, and nut on the bolts and tighten them loosely. Slide the BBADCP as far towards the tail as it will go (when the bolts on the end cap hit the mounting clamp). Orient the instrument so the fifth beam is in the center, pointing out perpendicular to the horizontal plane of the towed vehicle. Tighten the nuts on the mounting clamp completely.
- m.* Connect the 4-pin male molded-plastic connector on the CTD to OBS interconnect cable to its mate on the OBS, and screw down the locking sleeve.
- n.* Place the OBS in position with the LED sensor facing out through the hole. Put the hose clamp fitted in the slot in the towed vehicle around the OBS housing and tighten it. Put the U-bolt around the OBS with the two threaded ends through the holes in the towed vehicle, put on the washers and nuts, and tighten the bolt so it locks the OBS in place.

- o.* Place the ORE transponder on its mount with the transducer (i.e., the end with the flexible cover) through the hole. Put the hose clamps attached to the mounting bracket around the transponder and tighten them completely.
- p.* Use plastic cable ties to secure all the cables so they won't flap around when the system is under tow. Specific tie-down points are not provided, but sufficient places exist to secure the cables.
- q.* Set tires, or some other type of pads, on the deck. Turn the towed vehicle over and place it on the pads so that the transducer head assembly is not touching the deck or the pads.
- r.* Run the cable to the BBADCP along the top of the pressure case, turn the end in, and plug the 20-pin female connector into its mate on the top end cap of the BBADCP. Screw the locking ring down tight. Slide the fiberglass cover along the top of the BBADCP case, over the cable, and under the edges of the cut-out section, and place the end (looks like the head of a torpedo) over the ring on the BBADCP end cap and install the three screws through the cover into the ring. Tighten the screws completely to secure the cover.
- s.* Connect the 8-pin female connector at one end of the deck cable to the slipring assembly on the winch. Make sure the slipring assembly has a tie line to keep it from accidentally turning. Connect the other end of the deck cable to the connector (labeled "ADCP") on the back panel of the deck box. The ADCP connector is the one farthest to the right as you face the rear panel (see Appendix A).
- t.* Follow procedures *f* through *i* under the "Shallow-Water Configuration, Setup" procedures given above.
- u.* When fully assembled, as described above, the towed vehicle weighs about 350 lb in air. An "A"-frame or a strong davit is normally required to use the system. The armored cable should pass through a block at the top of the davit or A-frame. The block should be high enough off the deck so that the winch can be used to lift the towed vehicle up off the deck and swing it out over the water. Care should be taken to ensure that the transducer faces are not rubbed against the deck, railing, or side of the ship.
- v.* The system should be towed at the ship's minimum speed (usually about 3 knots). Cable can be paid out until, while under tow, the depth shown on the DAS (see Chapter 4, "DAS Data Acquisition and Playback") display screen is the desired depth. Generally, the ratio of cable paid out to tow depth is between 2 and 3. THE MAXIMUM DEPTH OF THE SENSOR'S PRESSURE HOUSINGS IS 1,000 m.

- w. Detailed information on mounting and deploying the Trackpoint II System can be found in the ORE Manual. It is not a simple task. When the ship is moving, there are very large forces on any bracket made to deploy the Trackpoint II transducer over the side of the ship.

4 Data Acquisition

Data Acquisition Software (DAS)

Data acquisition is through PLUMES Data Acquisition Software (DAS). DAS can also be used to replay and display data in the same format as that used during acquisition.

Firmware Setup Procedures

The performance of the BBADCP is under firmware control, configured by a series of commands. There are four ways in which these commands are installed, including (a) as default settings, (b) as fixed DAS commands, (c) as a command file, and (d) as DAS menu items. Appendix C in the RDI Manual gives a complete list of the commands that are not unique to PLUMES. The commands that are unique to PLUMES, the “K” and “V” commands, are described in Appendix E of this manual. The fixed DAS commands set the BBADCP clock from the computer clock with the TS command, and set the baud rate to 38400 with the CB611 command before sending the commands in the command file, PLUMES.CMD. The first command in PLUMES.CMD is the CR1 command, which instructs the system to use factory default settings unless they are subsequently modified by another command. DAS then sends the remaining commands that will alter factory default settings that are not DAS menu items. Entries in the DAS menu, as described in the section of this chapter called “Starting DAS,” make the last changes. Starting the data collection mode from the DAS menu sends the CS command.

The factory settings commonly changed with the commands in PLUMES.CMD are shown as they appear in a typical PLUMES.CMD file, as follows:

```
CR1
CF11110
WF50
VF75
ES34
ED2500
```

EX11110
EZ1011101
KE1
KN1
BP0

The commonly changed parameters and their commands that are DAS menu items are:

WN, VN Number of depth cells
WS, VS Depth cell size (vertical cm)
WP, VP Number of pings per ensemble

A detailed description of these commands can be found in Appendix C of the *RDI Manual*, and Appendix E in this manual. Of particular note is the BP command, which turns bottom tracking on (BP1) and off (BP0).

Hardware Requirements

The host computer running DAS and acquiring PLUMES data should be an IBM DOS-compatible computer with a 386 or higher processor. A hard disk is needed with sufficient free space to store the data until it can be transferred to an archival medium.

Starting DAS

Install DAS on the host computer as outlined above and type "ACQUIRE," and the <Enter> key. The screen shown in Figure 3 will appear. The operating parameters listed in the menu can be modified by entering the number of the item to be modified at the location of the cursor at startup, and entering the data at the prompt. Once an item is selected, the entire line of information must be entered before DAS will allow another entry. For example, if a "6" is entered to change the pings per ensemble, and only the number of velocity pings per ensemble is entered, DAS will not modify the item or allow another step until the number of intensity pings per ensemble is also entered. Entries for menu items requiring two parameters should be typed with a space between them and a single stroke of the <Enter> key after both items have been typed. Functions of the parameters for each menu item are described below.

1 - Transect Path Name (Incl. "\")

The data file will be stored on the drive and in the directory or subdirectory given by this item. A backslash (i.e., "\") must be between each directory and at the end of the entry.

BBADCP PLUMES TRANSECT PROGRAM	
1 - Transect Path Name (incl. "\")----	c:\dump\scow6\
2 - Transect File Name (no ext) -----	22dump1
3 - Transect File # (000-999) -----	0
4 - # Bins Velocity/Intensity -----	75 128
5 - Bin Len Velocity/Intensity (cm) --	100 75
6 - Pings/Ens Velocity/Intensity -----	1 4
7 - Display ave. time Vel/Int (# Ens.)	1 1
8 - Low/High Velocity Scale (cm/s) ---	-150 150
9 - Low/High Intensity Scale (dB) ----	0 70
10 - Time Range (s) -----	400
11 - Absorption Coeff. (dB/m 1-way)----	0.176
12 - Water Speed Layer 1st & Last Cell#	2 50
13 - Reference Velocity (cm/s) -----	0
14 - Nav filter constants (sec, fixes)	5 5
15 - Nav source (1 = fish, 2 = ship) --	2
20 - Start Transect	
30 - PlayBack Transect	
99 - Quit	
Enter Choice --->	

Figure 3. DAS menu

2 - Transect File Name (no ext)

The data file will have the name given by this item. The extension is assigned by DAS according to menu item 3.

3 - Transect File # (000-999)

The data file name given in menu item 2 will have the number given by this item as an extension. For example, the file for the menu given in Figure 3 would be 22dump1.000. When DAS is initially started, menu item 3 will be 0. The number is automatically incremented by one each time the data collection mode is entered.

4 - # Bins Velocity/Intensity

The number of depth bins for the four velocity beams and the number of depth bins for the intensity beam (i.e., the fifth beam) are given by this item. The minimum number is 1 and the maximum is 128.

5 - Bln Len Velocity/Intensity (cm)

The length, in centimeters, of each of the depth bins given for menu item 4 is given by this menu item.

6 - Pings/Ens Velocity/Intensity

The number of velocity pings per ensemble transmitted and processed for the four velocity beams is given by this item. Interleaving of the pings is discussed under the "VP" command in Appendix E.

7 - Display ave. time Vel/Int (# Ens.)

The number of ensembles of data used to calculate an average velocity component and an average backscatter intensity for display while in the data collection mode is given by this item.

8 - Low/High Velocity Scale (cm/s)

The maximum velocities, in centimeters per second, represented by the color scales on the monitor for currents going east (-) and west (+) and also going north (+) and south (-), are given by this item. Velocities greater than these will be displayed using the colors for the maximums given.

9 - Low/High Intensity Scale (dB)

Maximum and minimum relative backscatter intensities, in decibels, represented by the bottom and top of the intensity color scale, are given by this item. DAS uses a nominal coefficient for converting BBADCP counts to relative intensity. Negative values can be given.

10 - Time Range (s)

The time represented by one display screen in the data collection mode, in seconds, is given by this item.

11 - Absorption Coeff. (dB/m 1-way)

Backscatter intensity data are corrected for spreading and absorption losses for display only (the data files are not corrected). The absorption correction is described in Section 2, under "Sonar Equation." The absorption coefficient, in decibels/meter, is given by this item. The "1-way" refers to the fact that DAS multiplies the range by 2, to account for losses in the beam going out and in the return backscatter.

12 - Water Speed Layer 1st & Last Cell#

In the data collection mode, the average current velocity for a selected water layer below the instrument is displayed on the computer screen. Beginning and ending depth bins for this layer are given by this item.

13 - Reference Velocity (cm/s)

If there are no bottom tracking and no navigation data, the speed of the ship will be the value entered for this item. The velocity profiles displayed on the data collection and playback screen, and the speed of the water speed layer, described under item 12, will be calculated using the speed of PLUMES over the bottom that is entered for this item.

14 - Nav filter constants (sec, fixes)

The position of the ship or the towed vehicle is transmitted to the host computer by the navigation system. Velocity estimates are made from the difference in position between navigation fixes. The first constant to enter is the time constant (in seconds) of the one-pole filter used to smooth the noisy estimates. The second constant is the time spacing (in fixes) of the positions used to calculate the noisy velocity estimates. It is recommended that these two parameters be set to the same value if the navigation messages occur at a 1-sec update rate.

15 - Nav source (1 = fish, 2 = ship)

This item specifies which velocity the navigation system is transmitting to the host computer. This can be either the velocity of the ship or the velocity of the towed vehicle (i.e., the "fish").

20 - Start Transect

This item starts the data collection mode. When a "20" is entered, the screen will change to the one shown in Figure 4, and DAS will automatically start acquiring, displaying, and storing data.

30 - Playback Transect

This item starts a playback of data. When a "30" is entered, the screen changes to the one shown in Figure 4, and DAS will automatically start displaying the specified data file. Data will be displayed in the same manner as when collected, except that data will be presented on the screen at a much faster rate than when collected.

99 - Quit

This item ends the program. When "99" is entered, the screen is cleared and the DOS prompt appears.

When either menu item 20 or 99 is entered, the current values of the menu parameters are saved in a text file called "PLUMES.PRM." From the DOS command line, this file can be copied to a file of a different name for documentation or backup purposes if several parameters are expected to be changed. The baud rate and parity of the NMEA navigation message are changed by editing PLUMES.PRM. If no such file exists, ACQUIRE will create one with default values as soon as the data collection mode is entered.

DAS Data Acquisition and Playback

The screen displayed when DAS is in the data collection mode, or when playing back data, is shown in Figure 4. The items displayed on the screen are explained in Table 2. Below the numerical data are the three running displays showing the acoustic backscatter intensity for the fifth beam, and the east-west and north-south current velocities. To exit the data collection or playback mode, push "Esc" on the host computer keyboard. This will close the file in which data have been stored. When the "Esc" key is pushed, the DAS menu will be displayed. Item 3 on the menu, the file number, will be displayed with value 1 higher than the file just closed. To collect data in a new file on the same drive and with the same name, but with the next sequential extension number, enter 20. Data can be played back with changes in menu items 7 through 13. The display screen can also be exited by pushing the "<Enter>" key, but only after DAS has displayed the entire file. To exit before all the data have been displayed, hit the "Esc" key.

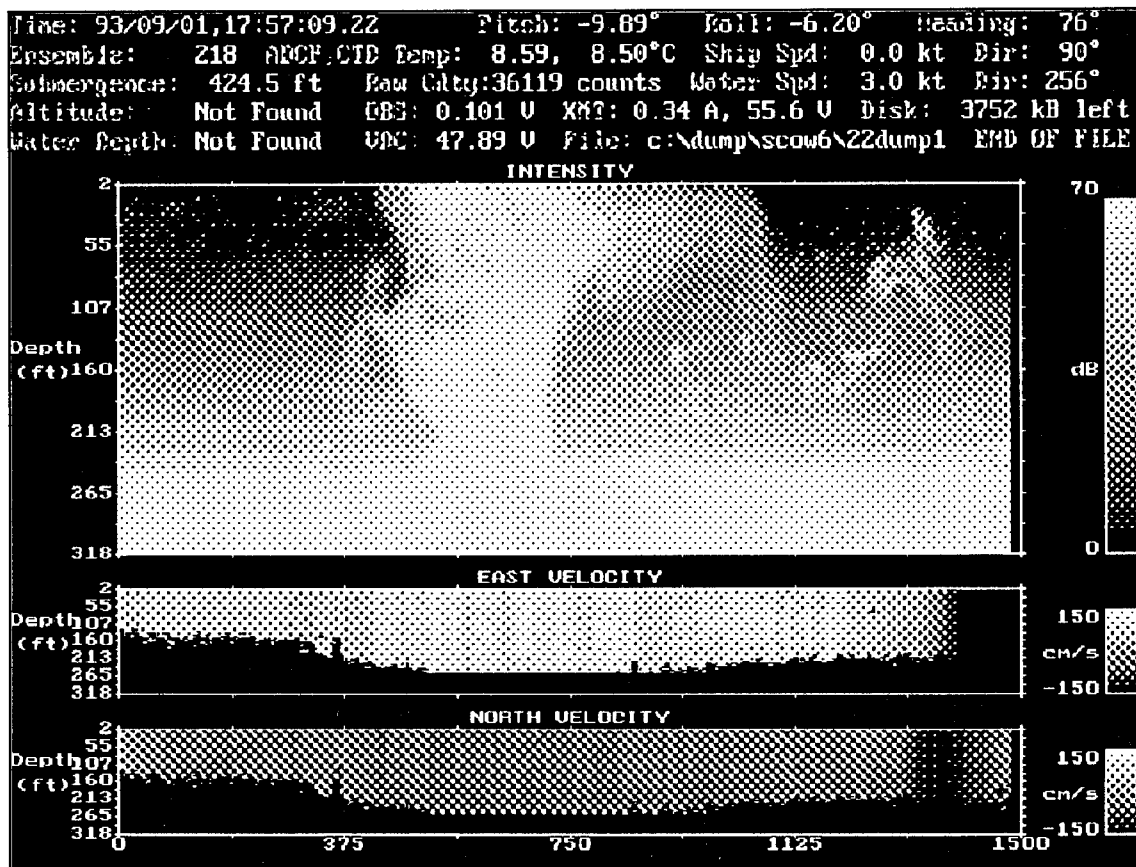


Figure 4. Screen displayed by DAS in the data collection and playback mode

Data Format

Data are stored in binary files that are opened and named using DAS. A file is closed when the operator terminates DAS. The data file consists of records of equal length, referred to as "ensembles," in binary format. The general format for the data is shown in Table 3, and a more detailed description can be found in Appendix D of the *RDI BBADCP Manual*. Formats of the data for the fifth beam and the CTD system are explained in greater detail below. See Table 3 for locations within the data files referred to below.

Header data

Address offset and data types. The address offsets for the fifth beam backscatter intensity, fifth beam setup information, CTD data, and navigation data, in that order, are stored in the locations for the last four data types in the "Header." Each is stored as a 2-byte number with the least significant byte first. Each number minus one is the absolute binary bite number in the ensemble where the identification code for data of that type begins. Each number plus one is the absolute binary bite number in the ensemble where data of that type begin.

Table 2
Information Shown on DAS Data Acquisition and Playback
Display

Displayed Description	Units	Meaning
Time	y/m/d, h,m,s	Current date and time referenced to the host computer clock
Pitch	Degrees	Forward/backward tilt of BBADCP, positive when forward-looking beam (beam 3) is up
Roll	Degrees	Sideward tilt of BBADCP, positive when starboard beam (beam 2) is down
Heading	Degrees	Compass direction of forward-looking beam, less offset entered by operator (firmware command). In towed configuration, this is the direction of motion of the towed body. In the boat-mounted configuration, this is the direction of motion of the boat
Ensemble	Count	The number of the profile measurement, the first profile in the record is 1
ADCP ¹ , CTD Temp.	Degrees Celsius	Temperature measured by temperature sensor mounted in BBADCP transducer head and by the CTD
Ship spd	Knots	Speed of the ship over the bottom. Works only when bottom tracking
Dir	Degrees	True direction of ship's travel over bottom, from BBADCP compass and operator-entered variation. Works only when bottom tracking
Submergence ¹	Feet	Depth of towed body. Fixed at 3.28 ft for the shallow-water configuration
Raw Ctdy ¹	Counts	CTD conductivity in counts before conversion to engineering units
Water Spd	Knots	Average current speed for bins 2, 3, and 4, over bottom when bottom tracking or less speed entered by operator when not bottom tracking
Direction	Degrees	Average current direction for bins 2, 3, and 4, magnetic, less offset entered by operator
Altitude	Feet	Distance from BBADCP to bottom, only when bottom tracking
OBS ¹	Volts	Output voltage of the optical backscatter sensor
XMT	Amps, volts	Current and voltage to the fifth beam transducer when transmitting a ping
Disk	Kilobytes	The amount of data storage capacity left on the drive specified in item 1 of the DAS menu
Water depth	Feet	Water depth, sum of "Submergence" and "Altitude." Works only when bottom tracking
VDC	Volts	Voltage at the input to the BBADCP
File	NA	Name of the file in which data are being stored
¹ Deepwater configuration only.		

Table 3
Ensemble Data File Format

Header	7F7F hex	% Good	2 bytes + 4 bytes per depth cell
	4 bytes	Status	2 bytes + 4 bytes per depth cell
	2 × (No. of data types - 4) bytes	Bottom Track	72 bytes
	5th beam backscatter intensity offset address - 2 bytes	5th Beam Backscatter Int.	010C hex
	5th beam setup information offset address - 2 bytes		
	CTD data offset address - 2 bytes		
	Navigation data offset address - 2 bytes	5th Beam Setup Information	1 byte per intensity depth cell
Fixed Leader	42 bytes		010F hex
	Variable Leader		37 bytes
ADCP temperature - 1 byte			No. of pings - 2 bytes
			Cell length - 2 bytes
			Blank after transmit - 2 bytes
			2 bytes
		VDC voltage - 1 byte	CTD Data
1 byte	New data flag - 2 bytes		
Velocity	2 bytes + 8 bytes per velocity depth cell	Temperature - 4 bytes	
	Correlation Magnitude	2 bytes + 4 bytes per velocity depth cell	
Data continues in next column of this table.		OBS - 4 bytes	
		Pressure - 4 bytes	
		Navigation Data	0012
			Format code - 2 bytes
			Julian day - 2 bytes
			Time - 4 bytes
			Longitude - 4 bytes
			Latitude - 4 bytes
East vel. - 2 bytes			
North vel. - 2 bytes			
		Check sum	Check sum - 2 bytes

Variable leader data

ADCP temperature. The temperature measured at the amplifier for the fifth beam, in the BBADCP, is stored in “ADC Channel 3” (see Appendix D in the RDI Manual). It is an unsigned count stored as a single byte. It can be converted to degrees Celsius by multiplying it by 1,419, subtracting 273,150, and dividing the result by 1,000.0. This temperature is used in calculating the source level and the reverberation level (see “Transmitted Signal” and “Receive Signal” sections in Chapter 2).

VDC voltage. The VDC voltage is stored in “ADC Channel 6” (see Appendix D in the RDI Manual). It is an unsigned count stored as a single byte. It can be converted to volts by multiplying it by 0.307. This voltage is used in calculating the source level (see the “Transmitted Signal” section in Chapter 2).

5th beam backscatter intensity data

Identification code. The identification code for fifth beam backscatter intensity is 010C hex.

Backscatter intensity. Backscatter intensity is stored in counts as single bytes. There is one for each depth cell, as given in the fifth beam setup information. The counts can be converted to db re 1 micro pascal at 1 m, if the receive sensitivity of the BBADCP’s fifth beam has been calibrated in an acoustic calibration test tank.

5th beam setup Information

Identification code. The identification code for the fifth beam setup information is 010F hex.

Number of depth cells. The number of depth cells for fifth beam backscatter intensity is stored as a single byte.

Number of pings. The number of intensity pings per ensemble is stored as 2 bytes, with the least significant byte first.

Depth cell length. The length of each depth cell in centimeters is stored as 2 bytes, with the least significant byte first.

Blank after transmit. The distance of the first cell away from the transducer head (i.e., the blanking distance) in centimeters is a half cell length further away from the transducer than the number stored at this location. It is stored as 2 bytes, with the least significant byte first.

CTD data

Identification code. The identification code for the CTD data is 0001 hex.

New data flag. The first byte is 1. The second byte is 1 when new data are stored, and 0 when previous data are copied.

CTD data. There are 20 bytes of CTD data. Each byte is the hex code for the ASCII character, which is the equivalent of the hex character for one nibble of data. For example, if the byte is 46 hex, it is the ASCII code for an "F," F hex is the value of the nibble stored. The CTD temperature in counts is stored in the first four bytes, with the most significant nibble first. For example, if after converting each byte to its equivalent hex value, as just described, the first four bytes represent F, 2, 8, and A, then the CTD temperature in counts is F28A hex. Conductivity in counts is stored in bytes 9 through 12, OBS readings in bytes 13 through 16, and pressure in bytes 17 through 20. CTD counts are converted to standard parameter values using CTD calibration information (see Appendix C).

Navigation data

Identification code. The identification code for navigation data is 0012 hex.

Julian day. The day navigation data were taken in days from 31 December of the previous year is stored as 2 bytes, with the least significant byte first.

Time. The time of day navigation data were taken in milliseconds from midnight is stored as 4 bytes, with the least significant byte first.

Longitude. Longitude is a signed number of milliarcseconds stored as 4 bytes, with the least significant byte first. The number is negative for locations west of Greenwich.

Latitude. Latitude is a signed number of milliarcseconds stored as 4 bytes, with the least significant byte first. The number is negative for locations south of the equator.

East velocity. East/west velocity as calculated by the navigation system in millimeters/second is a signed number stored as 2 bytes, with the least significant byte first. Velocity is either the ship's velocity or the towed vehicle's velocity, depending on which the navigation system is programmed to transmit to the host computer. The number is negative when the system is going toward the west.

North velocity. North/south velocity as calculated by the navigation system, in millimeters/second, is a signed number stored as 2 bytes, with the least significant byte first. Velocity is either the ship's velocity or the towed vehicle's velocity, depending on which the navigation system is programmed to transmit to the host computer. The number is negative when the system is going toward the south.

5 Data Postprocessing

PLUMES postprocessing programs are as follows:

- a.* BBLIST - a standard RD Instruments program used for PLUMES data to create ASCII files of current velocity profiles. When there is no bottom tracking, these are instrument-referenced velocities and bin depths.
- b.* BBVEL - produces earth-referenced current velocity profiles.
- c.* CTDDAT - produces profiles of salinity, temperature, and density from multiple files of data taken using the deepwater PLUMES configuration.
- d.* BAKINT - produces files of backscatter intensity from the fifth beam, correct for absorption and spreading losses as described in Chapter 2, under "Sonar Equation." The files also include the OBS reading for each ensemble processed.
- e.* CONCEN - an experimental program that produces files of suspended sediment concentration.

BBLIST

BBLIST is a standard RD Instruments program for converting raw binary data files to ASCII files and tabular displays of data in engineering units. An on-line manual for the program is provided with the software. The manual calls the fifth-beam intensity "vertical beam intensity." The raw binary data files created by DAS are the input files needed by BBLIST. For postprocessing PLUMES data, BBLIST is used to produce ASCII files of velocity data for BBVEL to process.

At two points in BBLIST, menu items need to be chosen for processing PLUMES data, and it may not be clear from the RDI Manual what should be entered. The first of these is shown in Figure 5. In the figure, the menu for "Process" has been opened and the "velocity Reference" item has been

highlighted. Pushing the space bar on the keyboard will toggle the choice between the two used for PLUMES ("ADCP" and "BTM TRACK" - "REF LAYER" is not used). "BTM TRACK" can be used when PLUMES was tracking bottom. BBLIST will reference the current velocities to the bottom track velocity and calculate the earth-referenced velocities. This is the most accurate way to determine the earth-referenced velocities. When PLUMES does not track bottom, this item should be "ADCP." BBLIST will then calculate the velocities relative to the BBADCP. These will be converted to earth-referenced velocities using navigation data by BBVEL. Note also that "Velocity units" is "ADCP." These are units of millimeters per second and are the correct units for processing by BBVEL.

File Process Display Convert				BBLIST 3.01			
Use <Spacebar> to choose velocity reference: ADCP, bottom-track, ref. layer							
Name				ENSEMBLE INFO IN DATA SET			
velocity Reference BTM TRACK				Number	Date	Time	
23DU	Magnetic variation	0.00	First	1	03-SEP-93	00:02:10	
23DU	Velocity units	ADCP	Last	544	03-SEP-93	07:05:12	
23DU	Depth units	ADCP					
23DU				ENSEMBLE INFO IN 23DUMP2.000			
23DUMP2	004	1,191,783	Number	Date	Time		
23DUMP2	005	182,103	First	1	03-SEP-93	00:02:10	
23DUMP2	006	1,155,723					
23DUMP2	007	751,851					
23DUMP2	008	980,832					
				RECORDED DATA			
				Leader			
				Velocity (earth)			
				Correlation			
				Intensity			
				Percent Good			
				CTD Data			
				Vertical beam (I)			
FORMAT FILE NAME				Ensemble size 1803 bytes			
F1-Help				F10-Screen			

Figure 5. Selecting bottom tracking as a reference velocity

Figure 6 shows the screen in which the format of the output files is chosen. This is the screen given when the "Convert" menu is opened and the "Define format" item is entered. The format shown is the correct one for producing files for BBVEL. It will produce an ASCII file of consecutive ensembles. For each ensemble, the ensemble number, followed by the time, will be given on the first line. An example is seen at the bottom, where the first ensemble of raw data file 23DUMP2.000 is shown; it is: 1 00:02:10. This will be followed by the current speed and direction, one to a line for each bin. The file must be in this format for input to BBVEL.

File Process Display Convert

BBLIST 3.01

Use <↑><↓><←><→> to move bar, <Enter> to change fields, <F9> to view format

FORMAT FILE DEFAULT.FMT

	1	2	3	4	5	6	7
1	ENS no.	Time str	LINE END				
2	Mag 1	Dir 1	LINE END				
3	Mag 2	Dir 2	LINE END				
4	Mag 3	Dir 3	LINE END				
5	Mag 4	Dir 4	LINE END				
6	Mag 5	Dir 5	LINE END				
7	Mag 6	Dir 6	LINE END				
8	Mag 7	Dir 7	LINE END				
9	Mag 8	Dir 8	LINE END				
10	Mag 9	Dir 9	LINE END				
11	Mag 10	Dir 10	LINE END				
12	Mag 11	Dir 11	LINE END				
13	Mag 12	Dir 12	LINE END				
14	Mag 13	Dir 13	LINE END				

Line: no. 1 total length 16

Field: no. 1 len. 5

'Ensemble number'

Format 'XXXXX'

— Data from Z3DUMP2.000 :

1 00:02:10

1.....2.....3.....4.....5.....6.....7.....8

F1-Help <—Change F5/F6-SizeLeft

F9-View F10-Menu

Figure 6. File format for velocity data

BBVEL

When the velocity profile files produced by BBLIST do not contain earth-referenced velocities determined using bottom tracking, they need to be corrected for the velocity of the system over the bottom. This can either be accomplished using the position data in the PLUMES data files (see Table 2) or, it can be done with a separate navigation file. The option of using a separate navigation file makes it possible to use navigation data that have been postprocessed for correction or filtering. The velocity data files produced by BBLIST have no information in them regarding the depth range of the profile. This must be determined from the CTD data in the raw PLUMES data file. The BBVEL program uses the current speed and direction data files produced by BBLIST, raw PLUMES data files, optional navigation files, and a CTD calibration file to produce earth-referenced current velocity profile files referenced to the measured depth of the towed vehicle.

Data in a navigation file are matched with the corresponding PLUMES data by the time. The navigation files must be in ASCII format with one observation of time and position in latitude and longitude per line. A line with this information on it must be identified by the presence of a particular number, letter, or character at a position on the line that does not change throughout the file. The character and its position are specified in the start menu. The character can appear at this location on the line, only when the line contains the required time and position data. The date must be in days, months, and years,

and time must be in hours (24-hr clock), minutes, and seconds, and each must take up two spaces on the line. Latitude and longitude must be in degrees (north latitude and west longitude), minutes, and seconds. Degrees west longitude must use three spaces on the line. Degrees north latitude and minutes (longitude and latitude) must use two spaces. If seconds includes a decimal point, the number of digits after the decimal point must be specified in the start menu. The location of these data on each line is specified in the start menu, and must not change throughout the file.

The start menu is shown in Figure 7. The processing parameters listed in the menu can be modified by entering the number of the item to be modified at the location of the cursor at start-up, and entering the data at the prompt. Items with more than one entry, such as "7 - Start, end ensemble no." can have the items separated with a space, comma, or backslash. A single stroke of the <Enter> key should be made after both items have been typed. Functions of the parameters for each item are described below.

1 - BBLIST velocity file

Path and file for velocity profile data that were produced by BBLIST.

2 - PLUMES data file

Path and file for the raw PLUMES data file.

3 - Bot. trk. (1) or ADCP (2) ref.

If PLUMES was tracking bottom, and bottom tracking was selected as the reference velocity, then enter "1." The default value when the program is started is 2.

4 - Fish (1) or file (2) navigation

If a separate navigation file will be the source of the position data, enter "2." The default value when the program is started is 1.

5 - Navigation file

Path and file for the navigation data.

6 - Output file

The path and file for the processed output data.

BBVEL START MENU

- | | |
|-------------------------------------|--------------------------------|
| 1 - BBLIST velocity file | -C:\PLUMES\SANFRAN\dump1bb.000 |
| 2 - PLUMES data file | -C:\DATA\SANFRAN\22dump1.000 |
| 3 - Bot. trk. (1) or ADCP (2) ref. | -2 |
| 4 - Fish (1) or file (2) navigation | -2 |
| 5 - Navigation file | -C:\PLUMES\NAVIGAT\dump1 |
| 6 - Output file | -C:\PLUMES\PROCESS\dump1.vel |
| 7 - Start, end ensemble no. | -33,133 |
| 8 - No. of output ens. avg./profile | -10 |
| 9 - CTD calibration file | -C:\PLUMES\CTD\sbe16.893 |
| 10 - Depth on deck (ft) | -1.2 |
| 11 -Nav. line char. and position | -[,1 |
| 12 -1st position - day,mo,yr | -2,5,8 |
| 13 -1st position - hr,min,sec | -10,12,14 |
| 14 -1st position lat - deg,min,sec | -16,18,20 |
| 15 -1st position lon - deg,min,sec | -26,29,31 |
| 16 -Number of digits after decimal | -3 |

20 - Start processing data

99 - Quit

Enter choice --->

Figure 7. BBVEL start menu

7 - Start, end ensemble no.

The range of ensemble numbers within the file to process is specified by this item. If the start number is outside the range of values of ensembles present in the data file, BBVEL will stop without producing data in the output file. If the end value is greater than the number of ensembles in the data file, BBVEL will process all the ensembles in the data file from the start ensemble to the last ensemble in the file. The end ensemble number cannot be greater than 32767.

8 - No. of output ens. avg./profile

Data for the number of ensembles specified by this item will be averaged together to produce an average current velocity profile. For example, if item 7 was 1,20 and this item was 10, the output would be two ensembles, one the

average of ensembles 1 through 10 and the other the average of ensembles 11 through 20.

9 - CTD calibration file

Path and file containing the CTD calibration data.

10 - Depth on deck (ft)

Before and after the towed vehicle is deployed, the submergence reading on the DAS data acquisition screen when the towed vehicle is on the deck should be recorded. The average of the before and after values should be entered for this item. BBVEL subtracts this value from the depth data to correct the values for this zero offset.

11 - Nav. line char. and position

The character and its position on the navigation data line which identify the line as one having the required navigation data is specified by this item.

12 - 1st position - day,mo,yr

Position on the navigation data line which has the first digit of the day, the first digit of the month, and the first digit of the year for the date the location of the ship or towed vehicle was fixed.

13 - 1st position - hr,min,sec

Position on the navigation data line which has the first digit of the hour, the first digit of the minute, and the first digit of the second for the time the location of the ship or towed vehicle was fixed.

14 - 1st position lat - deg,min,sec

Position on the navigation data line which has the first digit of the degrees, the first digit of the minutes and the first digit of the seconds of north latitude of the ship or towed vehicle location.

15 - 1st position lon - deg,min,sec

Position on the navigation data line which has the first digit of the deg, the first digit of the minutes and the first digit of the seconds of west longitude of the ship or towed vehicle position.

16 - Number of digits after decimal

If the seconds of latitude and longitude is a decimal number, the number of digits after the decimal is entered for this item. For example, if longitude is 123 45 27.234 and latitude is 33 22 15.012, then this item is 3. If there is no decimal point, enter a 0 for this item.

20 - Start processing data

This item starts the processing of data.

99 - Quit

This item ends the program.

The BBVEL output file contains the following three lines of ASCII data for each processed velocity output profile:

Header line

EEEE AAA DD MO YR HH MM SS UUUU.U BBB LLL

EEEE is the ensemble number of the first ensemble of the ensembles averaged to produce the average velocity profile.

AAA is the number of ensembles averaged to produce the average velocity profile.

DD is the day the data for the first ensemble used for the average were taken.

MO is the month the data for the first ensemble used for the average were taken.

YR is the year the data for the first ensemble used for the average were taken.

HH is the hour (24-hr clock) the data for the first ensemble used for the average were taken.

MM is the minute the data for the first ensemble used for the average were taken.

SS is the second the data for the first ensemble used for the average were taken.

UUUU.U is pressure at the depth of the towed vehicle less atmospheric pressure in decibars (approximately equal to meters below the sea surface).

BBB is the number of bins of velocity data in a profile.

LLL is the vertical length of each bin in centimeters.

Current direction line

DDD DDD

DDD is the direction the current is going toward; one for each bin.

Current speed line

SSS.S SSS.S

SSS.S is the current speed in cm/sec; one for each bin.

CTDDAT

In the deepwater configuration, PLUMES records CTD data every 15 sec. Each update is for a single depth. The towed vehicle is normally towed over a narrow range of depths for a period of time and then lowered to another depth where it is again towed over a narrow range of depths. This procedure is usually repeated several times during a monitoring operation, and the result is CTD data recorded in several raw PLUMES data files, covering the full range of depths at which the system was towed. If the conditions are such that the seawater properties are relatively uniform horizontally and don't vary too much with time, a single profile, representative of the location and time of the monitoring, can be assembled from the data stored in files. The CTDDAT program uses multiple raw PLUMES data files and the CTD calibration file to produce a single average profile of water properties. The format of the CTD calibration file is contained in Appendix C. The maximum pressure of the profile is 1,000 decibars (approximately the same as depth in meters).

The start menu for CTDDAT is shown in Figure 8. Processing parameters listed in the menu can be modified by entering the number of the item to be modified at the location of the cursor at start-up, and entering the data at the prompt. Items with more than one entry, such as "7 - Start, end ensemble

CTDDAT START MENU	
1 - PLUMES data file	-C:\DATA\SANFRAN\22dump1.000
2 - Start, end ensemble no.	-1,2302
3 - Create (1) or add to (2) output	-2
4 - Output file	-C:\PLUMES\SANFRAN\dump.ctd
5 - CTD calibration file	-C:\PLUMES\CTD\sbe16.893
6 - Depth on deck (ft)	-1.2
20 - Start processing data	
99 - Quit	
Enter choice --->	

Figure 8. CTDDAT menu

no.," can have the items separated with a space, comma, or backslash. A single stroke of the <Enter> key is made after both items have been typed. Functions of the parameters for each item are described below.

1 - PLUMES data file

The path and file for the raw PLUMES data file.

2 - Start, end ensemble no.

The range of ensemble numbers within the file to process is specified by this item. If the start number is outside the range of values of ensembles present in the data file, CTDDAT will stop without producing data in the output file. If the end value is greater than the number of ensembles in the data file, CTDDAT will process all the ensembles in the data file from the start ensemble to the last ensemble in the file. The end ensemble number cannot be greater than 32767.

3 - Create (1) or add to (2) output

Only one raw PLUMES data file is processed per run. A run is initiated by entering a 20. When processing multiple files, CTDDAT will take data from the current selected raw PLUMES data file and data already processed from the output file, recalculate average parameter values, and add to the profile when data at new depths are processed. When processing the first in a sequence, or when processing only a single file, enter a "1" for this item. When processing additional files to produce a single average profile, enter a "2" for this item.

4 - Output file

Path and file for the processed output data.

5 - CTD calibration file

Path and file containing the CTD calibration data.

6 - Depth on deck (ft)

Before and after the towed vehicle is deployed, the submergence reading on the DAS data acquisition screen when the towed vehicle is on the deck should be recorded. The average of the before and after values should be entered for this item. CTDDAT subtracts this value from the depth data to correct the values for this zero offset.

20 - Start processing data

This item starts the processing of data.

99 - Quit

This item ends the program.

The CTDDAT output file contains ASCII data for the average temperature, salinity, and density, for 1,000, 1-db (m) depth bins. The parameters are calculated from the CTD data using the equations in Chapter 2, under "Water Property Measurements." Also, the standard deviation and number of individual data values used to calculate each parameter at each depth are recorded. Where no data were processed for a depth, zeros are recorded in the output file. There is one line of parameter values, and numbers of values averaged, per 1-decibar (m) depth bin for all 1,000 bins. The depth is not recorded on a line, but it corresponds to the number of the line in the file. For example,

line 3 in the file corresponds to data for 3.0 to 4.0 decibars (m). Each line is as follows:

TT.T AA.A LLLL.L SS.S BB.B MMMM.M DD.D CC.C NNNN.N

TT.T is the average temperature in degrees Celsius.

AA.A is the standard deviation of the individual temperature values at that depth.

LLLL.L is the number of individual temperature values at that depth.

SS.S is the average salinity in parts per thousand.

BB.B is the standard deviation of the individual salinity values at that depth.

MMMM.M is the number of individual salinity values at that depth.

DD.D is the average density anomaly (i.e. $(1.0 - \text{density}) \times 1,000$) in kilograms per cubic meter.

CC.C is the standard deviation of the individual density values at that depth.

NNNN.N is the number of individual density values at that depth.

BAKINT

Backscatter intensity for the fifth beam needs to be corrected for spreading losses, using Equation 5 in Chapter 2, under "Sonar Equation," and for absorption, using Equation 6 in the same section. The BAKINT program uses PLUMES data files and the average water properties profile produced by CTDDAT to produce a file of backscatter intensities corrected for these losses. BAKINT also puts the OBS reading in the output file with each ensemble of acoustic backscatter data. The depth of the towed vehicle is calculated by BAKINT for the deepwater configuration using the CTD data and the CTD calibration file. For the shallow-water configuration, the depth is fixed at 1 m. The position at which the data were taken is recorded in the output file. BAKINT gets the position data either from the PLUMES data files (see Table 3) or from a separate navigation file. The format of the navigation file is described in this chapter under "BBVEL." The option to have no position data recorded is allowed. BAKINT also produces a second output file of uncorrected backscatter intensities used as input to CONCEN.

The start menu for BAKINT is shown in Figure 9. Processing parameters listed in the menu can be modified by entering the number of the item to be

BAKINT START MENU	
1 - PLUMES data file	-C:\DATA\SANFRAN\22dump1.000
2 - Start, end ensemble no.	-1,2302
3 - Output files	-C:\PLUMES\SANFRAN\22baki1.000
4 - Fixed (1) or calc. (2) absorb.	-2
5 - One-way absorb. coef. (db/m)	-
6 - CTD average profile file	-C:\PLUMES\SANFRAN\dump.ctd
7 - CTD calibration file	-C:\PLUMES\CTD\sbe16.893
8 - Depth on deck (ft)	-1.2
9 - Conversion factor (db/count)	-.406
11 -Noise count	-34
11 -Fish (1), file (2), or no (3) nav	-2
12 -Navigation file	-C:\PLUMES\NAVIGAT\dump1
13 -Nav. line char. and position	-[,1
14 -1st position - day,mo,yr	-2,5,8
15 -1st position - hr,min,sec	-10,12,14
16 -1st position lat - deg,min,sec	-16,18,20
17 -1st position lon - deg,min,sec	-26,29,31
18 -Number of digits after decimal	-3
20 - Start processing data	
99 - Quit	
Enter choice --->	

Figure 9. BAKINT start menu

modified at the location of the cursor at start-up, and entering the data at the prompt. Items with more than one entry, such as "7 - Start, and ensemble no.," can have the items separated with a space, comma, or backslash. A single stroke of the <Enter> key is made after both items have been typed. Functions of the parameters for each item are described below.

1 - PLUMES data file

Path and file for the raw PLUMES data file.

2 - Start, end ensemble no.

The range of ensemble numbers within the file to process is specified by this item. If the start number is outside the range of values of ensembles present in the data file, BAKINT will stop without producing data in the output file. If the end value is greater than the number of ensembles in the data file, BAKINT will process all the ensembles in the data file from the start ensemble to the last ensemble in the file. The end ensemble number cannot be greater than 32767.

3 - Output files

Path and file for the processed output data files. Either a "U" (for uncorrected) or a "C" (for corrected) will be placed in the third position after the "." in the output file names. If something is entered here in that position, it will be dropped. Missing characters in the first or second positions after the period will be replaced with zeros. If the period is missing, it will be added.

4 - Fixed (1) or calc. (2) absorb.

Output backscatter intensity files can be produced without using CTD data by using a fixed, representative value, for the absorption coefficient. This can be implemented by entering a "1" for this item. To calculate the absorption coefficient, water property data are required. When a "2" is entered for this item, BAKINT does the calculations using water property data from the CTD average profile.

5 - One way absorb. coef. (decibels per meter)

If a "1" was entered in item 4, the fixed value for the one-way absorption coefficient is entered for this item. "One-way" refers to the fact that DAS multiplies the range by 2, to account for losses in the beam going out and in the return backscatter. If a "2" was entered in item 4, anything entered for this item will be ignored.

6 - CTD average profile file

Path and the file containing the average CTD profile produced by CTDDAT. If a "1" was entered for item 4, anything entered for this item will be ignored.

7 - CTD calibration file

Path and file containing the CTD calibration data.

8 - Depth on deck (ft)

Before and after the towed vehicle is deployed, the submergence reading on the DAS data acquisition screen when the towed vehicle is on the deck should be recorded. The average of the before and after values should be entered for this item. BBVEL subtracts this value from the depth data to correct the values for this zero offset.

9 - Conversion factor (db/count)

The loss terms need to change to equivalent relative counts to add to the BBADCP data. This value can come from the BBADCP calibration (see Appendix C), or a nominal value can be used. The recommended nominal value is shown in Figure 9 (i.e., 0.406).

10 - Noise count

When the backscatter intensity falls below the system noise, the ADC counts for the fifth beam to stay constant. Applying a correction for geometrical spreading loss to noise in bins far from the transducer gives a meaningless large number for intensity, and processing of data along the beam should stop when the return signal falls below the noise level. The noise level is different for different operating conditions and needs to be specified. It is recommended that BBLIST should be used to view the fifth beam intensities for a location away from any plumes. The place along the beam where the counts become constant or change only slightly with increasing bin number can be located visually. The counts at this place along the beam should be entered for this item.

11 - Fish (1), file(2), or no (3) nav.

If a separate navigation file will be the source of the position data, enter a "2." If the source is the navigation data stored in the PLUMES raw data file, enter a "1" for this item. If there are no position data, enter a "3" for this item.

12 - Navigation file

Path and file for the navigation data.

Items 13, 14, 15, 16, 17, and 18

These items are described in the section on BBVEL.

20 - Start processing data

This item starts the processing of data.

99 - Quit

This item ends the program.

The BAKINT output files (both the one for corrected data and the one for uncorrected data) contain two lines of ASCII data for each processed ensemble in the range of ensemble numbers specified. These are as follows:

Header line

```
eeee dd mm yy hh qq ss nn pp ww.www aaa cc xx.xxx uuuu.u o.ooo bbb  
lll zzz vv.v k.kk
```

eeee is the ensemble number.

dd is the day data were taken.

mm is the month data were taken.

yy is the year data were taken.

hh is the hour (24-hr clock) data were taken.

qq is the minute data were taken.

ss is the second data were taken.

nn is the degrees of north latitude for the location at which data were taken.

pp is the minutes of north latitude for the location at which data were taken.

ww.www is the seconds of north latitude for the location at which data were taken.

aaa is the degrees of west longitude for the location at which data were taken.

cc is the minutes of west longitude for the location at which data were taken.

xx.xxx is the seconds of west longitude for the location at which data were taken.

uuuu.u for the deepwater configuration, is pressure at the depth of the towed vehicle, less atmospheric pressure in decibars (approximately equal to meters below the sea surface). For a shallow-water configuration, this depth is fixed at 1 m.

o.ooo is the OBS voltage.

bbb is the number of bins of fifth-beam intensity data in the ensemble.

lll is the vertical length of each bin in centimeters.

zzz is the blanking distance in centimeters.

vv.v is the fifth beam transmitter voltage in volts (used by CONCEN).

k.kk is the ADCP temperature in degrees Celsius (used by CONCEN).

Backscatter Intensity data line

III III III

III is corrected backscatter intensity in counts for each bin in the file for corrected data, and uncorrected backscatter intensity for the uncorrected data.

CONCEN

The CONCEN program calculates suspended sediment concentrations by applying the theories in Chapter 2, under "Rayleigh Scattering" and "Sonar Equation," to acoustic backscatter data in output files from BAKINT. It applies only to cases where the input grain-size distribution is known and can reasonably be assumed not to change or where the changes can be calculated (see Chapter 2, "Grain-Size Distribution," for more in-depth discussion).

The program is experimental and results obtained should be interpreted in light of the discussion in Chapter 2, "Grain-Size Distribution."

CONCEN uses the BAKINT output files of uncorrected backscatter intensities, a grain-size distribution file, a BBADCP calibration file, the average water properties profile produced by CTDDAT, and optionally, a background intensity file, to produce a file of concentrations for each ensemble processed. When a plume is being tracked, it will be present multiple times in a single BAKINT file, and/or will be in multiple BAKINT files. In the plume tracking mode, CONCEN is run only for a narrow range of ensembles that include the plume being tracked. If the plume is present multiple times in the same file, CONCEN must be run once for every time the plume is observed, each time only for a narrow range of ensembles that include the plume once. Formats of the grain-size distribution, BBADCP calibration, and background intensity files

are contained in Appendix C. There is an option for specifying constant water temperature, salinity, and density, instead of using the average CTD profile.

The start menu for CONCEN is shown in Figure 10. Processing parameters listed in the menu can be modified by entering the number of the item to be modified at the location of the cursor at start-up, and entering the data at the prompt. Items with more than one entry, such as "7 - Start, end ensemble no.," can have the items separated with a space, comma, or backslash. A single stroke of the <Enter> key is made after both items have been typed. Functions of the parameters for each item are described below.

1 - BAKINT data file

Path and file for the uncorrected fifth beam backscatter intensity data produced by BAKINT.

CONCEN START MENU	
1 - BAKINT data file	-C:\PLUMES\SANFRAN\22baki.00U
2 - Start, end ensemble no.	-346,567
3 - Output file	-C:\PLUMES\SANFRAN\22conc.000
4 - BBADCP calibration file	-C:\PLUMES\BBADCP\F600.443
5 - Fixed prop. (1) or CTD file (2)	-2
6 - CTD average profile file	-C:\PLUMES\SANFRAN\dump.ctd
7 - Temperature (deg C)	-
8 - Salinity (ppt)	-
9 - Density (kg/m cubed)	-
10 - Grain-size distribution file	-C:\PLUMES\SANFRAN\dump1.grs
11 - Select (1) or file (2) backgrnd.	-1
12 - Background file	-
13 - Background ensemble number	-10
14 - Time of dump (hr,min,sec)	-12,34,23
15 - Depth of top (m)	-0
20 - Start processing	
99 - Quit	
Enter choice --->	

Figure 10. CONCEN menu

2 - Start, end ensemble no.

The range of ensemble numbers within the file to process is specified by this item. If the start number is outside the range of values of ensembles present in the data file, CONCEN will stop without producing data in the output file. If the end value is greater than the number of ensembles in the data file, CONCEN will process all the ensembles in the data file from the start ensemble to the last ensemble in the file. The end ensemble number cannot be greater than 32767. CONCEN is only run for a narrow range of ensembles that includes the plume being monitored.

3 - Output file

Path and file for the processed output data.

4 - BBADCP calibration file

Path and the file containing acoustic calibration information for the BBADCP.

5 - Fixed prop. (1) or CTD file (2)

Data processing requires water property information. This can either come from the average CTD profile produced by CTDDAT (enter a "2" for this option), or fixed and constant values can be used (enter a "1" for this option). The default value is 2.

6 - CTD average profile file

Path and file for the average CTD-profile data produced by CTDDAT.

7 - Temperature (deg C)

If the option in item 5 was chosen to enter fixed and constant water property values, the water temperature in degrees Celsius is entered for this item.

8 - Salinity (ppt)

If the option in item 5 was chosen to enter fixed and constant water property values, the salinity in parts per thousand is entered for this item.

9 - Density (kg/m cubed)

If the option in item 5 was chosen to enter fixed and constant water property values, the density in kilograms per cubic meter is entered for this item.

10 - Grain-size distribution file

Path and file containing the grain-size distribution data.

11 - Select (1) or file (2) backgrd.

If the file being processed has data from outside the plume, then an ensemble of this data should be selected to be the background intensity (enter a "1" for this option). If there isn't an ensemble containing background intensities at a location away from the plume(s), then it will be necessary to use a file with background data in it (enter a "2" for this option). The default value is 2.

12 - Background file

Path and file for the background data.

13 - Background ensemble number

Number of the ensemble with data from a location outside of where there was suspended sediment. Computer processing time is reduced if an ensemble near the beginning of the file is selected.

14 - Time of dump (hr,min,sec)

Hour, minute, and second the disposed material being tracked was dumped, or, to use a grain-size distribution from a sample taken in the plume after the dump, enter the time the sample was taken.

15 - The depth of top (m)

Depth of the top of the plume. This is used to calculate the depth to which the particles have fallen since the grain-size distribution was determined (item 14). To utilize the grain-size distribution from the file specified under item 10 for calculations with no changes for particle settling, enter a negative number for this item. The exact value of the negative number is inconsequential. The depth in meters is entered for this item.

20 - Start processing data

This item starts the processing of data.

99 - Quit

This item ends the program.

The format of the output file for CONCEN is nearly the same as that for BAKINT. There are two lines of data for every ensemble. The first line is the same as for BAKINT. The format for the second line is:

CCCCC CCCCC.....

CCCCC is the suspended sediment concentration in milligrams per liter.

Data Presentation

Examples of presentations of data that can be produced from the output files of the postprocessing programs are given in this section. Figure 11 shows a velocity profile which was produced using BBVEL. Data were taken with a 600-kHz system in the deepwater configuration, and earth-referenced by BBVEL using a navigation file that consisted of smoothed towed-vehicle position fixes produced by a DGPS and an ORE Trackpoint II Range and Bearing system. Figure 12 shows water property profiles produced from approximately 45 hr of CTD data using CTDDAT. Figure 13 shows a cross section of acoustic backscatter profiles produced using output files from BAKINT. Data are shown dimensionally correct, both horizontally and vertically.

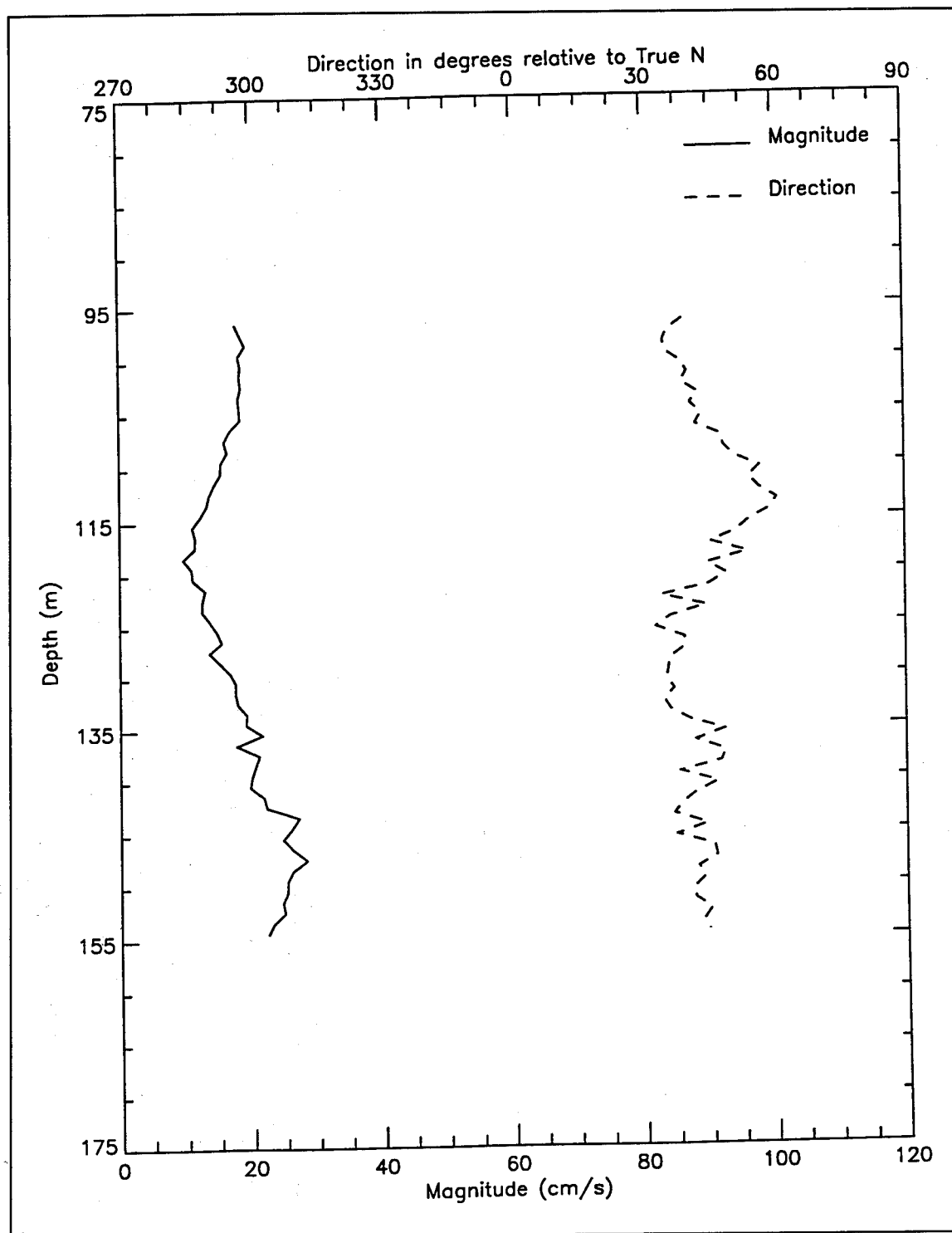


Figure 11. Velocity profile produced with BBVEL

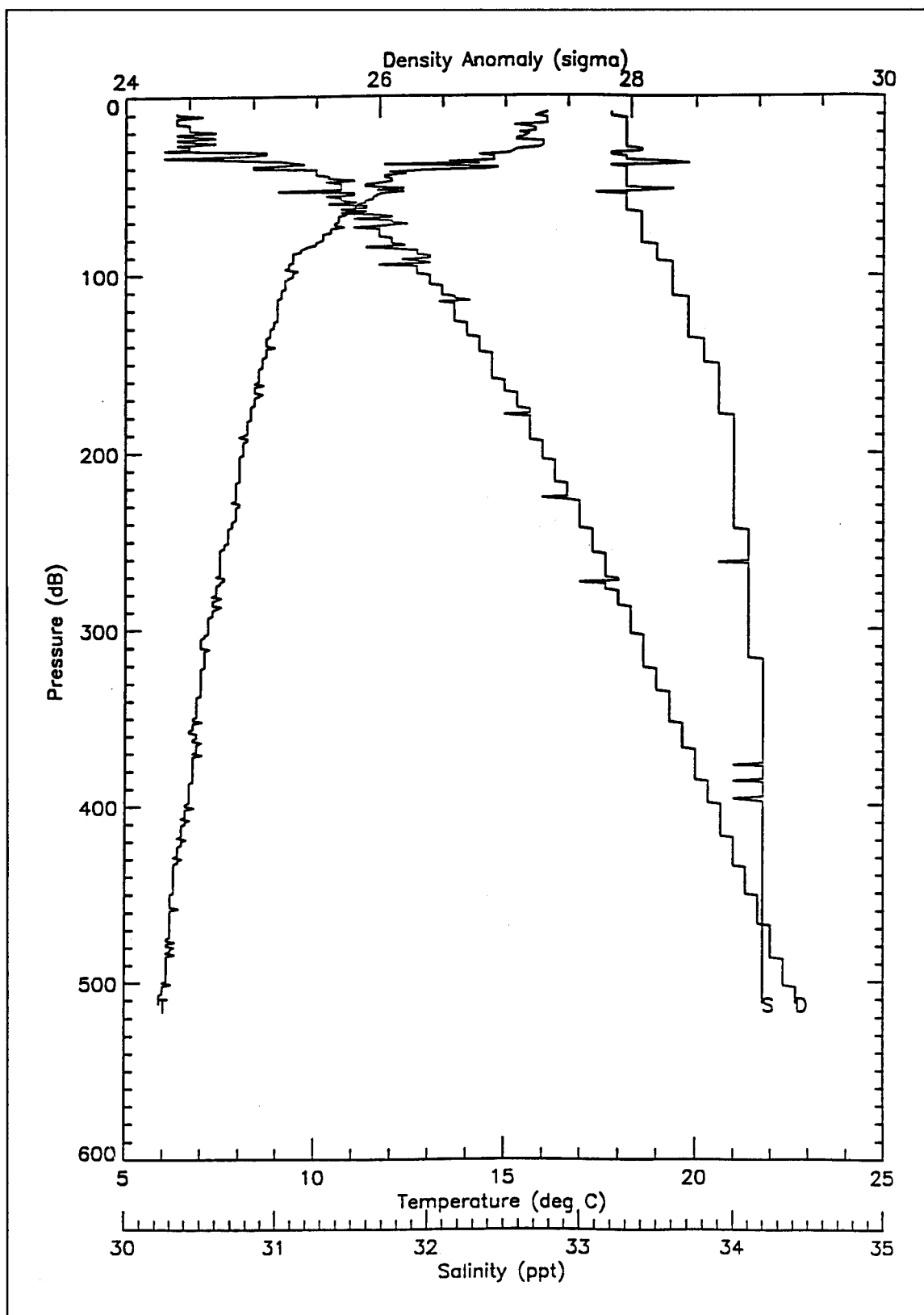


Figure 12. Water property profiles produced with CTDDAT

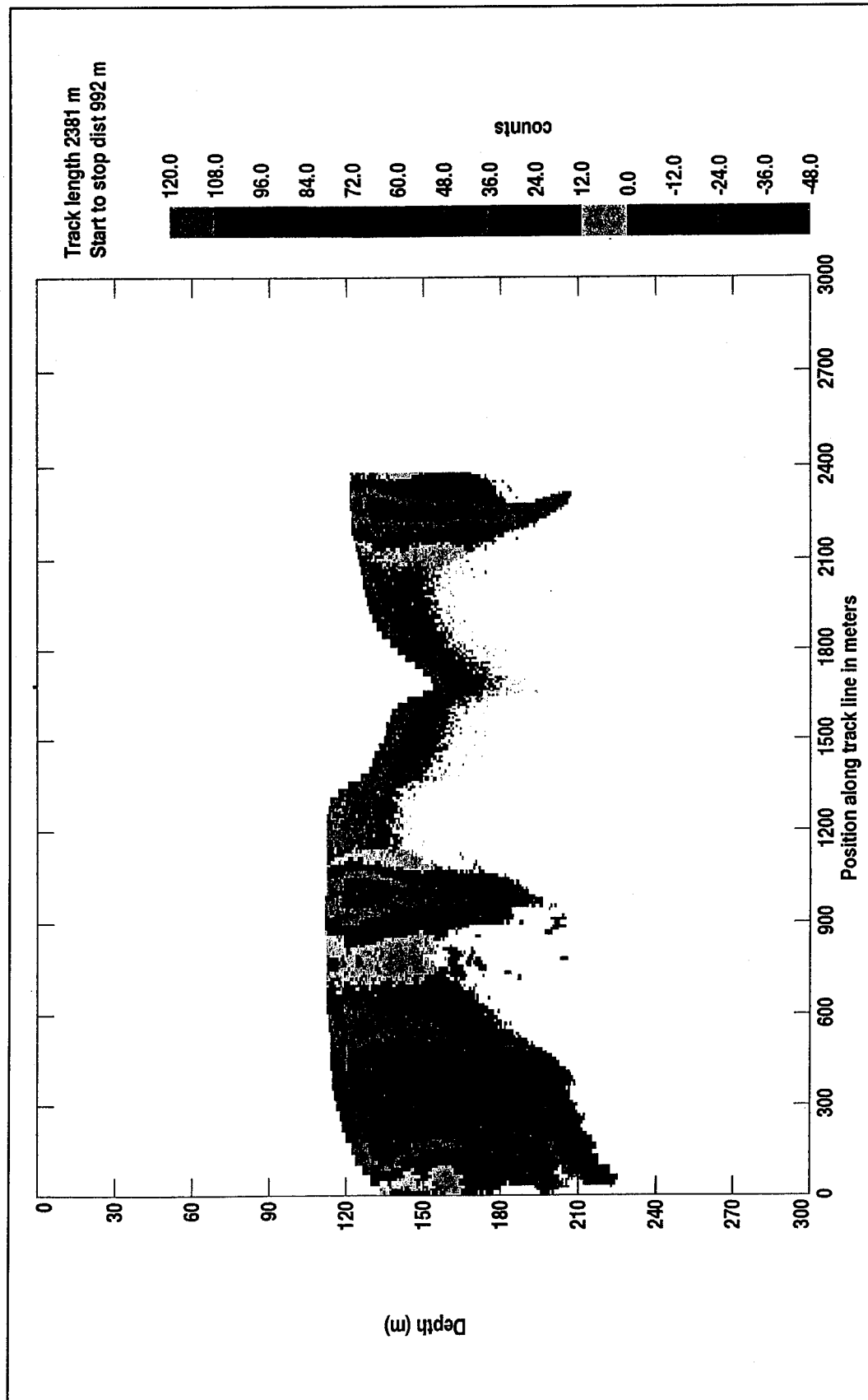


Figure 13. Acoustic backscatter profiles produced with BAKINT

References

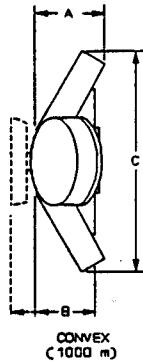
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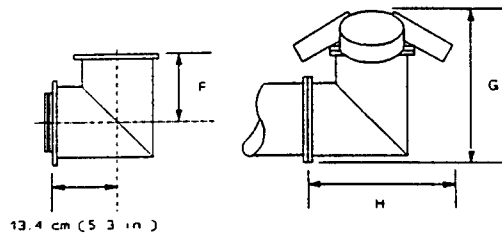
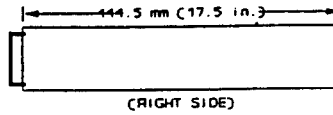
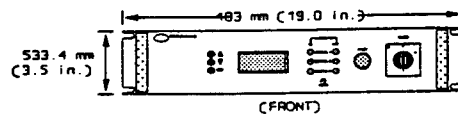
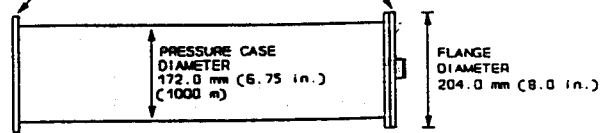
Appendix A

BBADCP Mechanical Specifications for PLUMES

The drawings in this appendix were prepared by RD Instruments for a vertical-beam broad-band acoustic Doppler current profiler (BBADCP) system.



FLANGE AND END-CAP WIDTHS = 13.0 mm (0.5 in.)



NOTES

1. CONSTRUCTION MATERIAL ASSUMED TO BE ALUMINUM
2. SEE NEXT PAGE FOR BREAKDOWN OF DIMENSIONS AND WEIGHTS.

System kHz	A mm	B mm	C mm	F mm	G mm	H mm	Case Length mm
600	108	122	377	166	374	323	345

System Weights

Shallow-water configuration

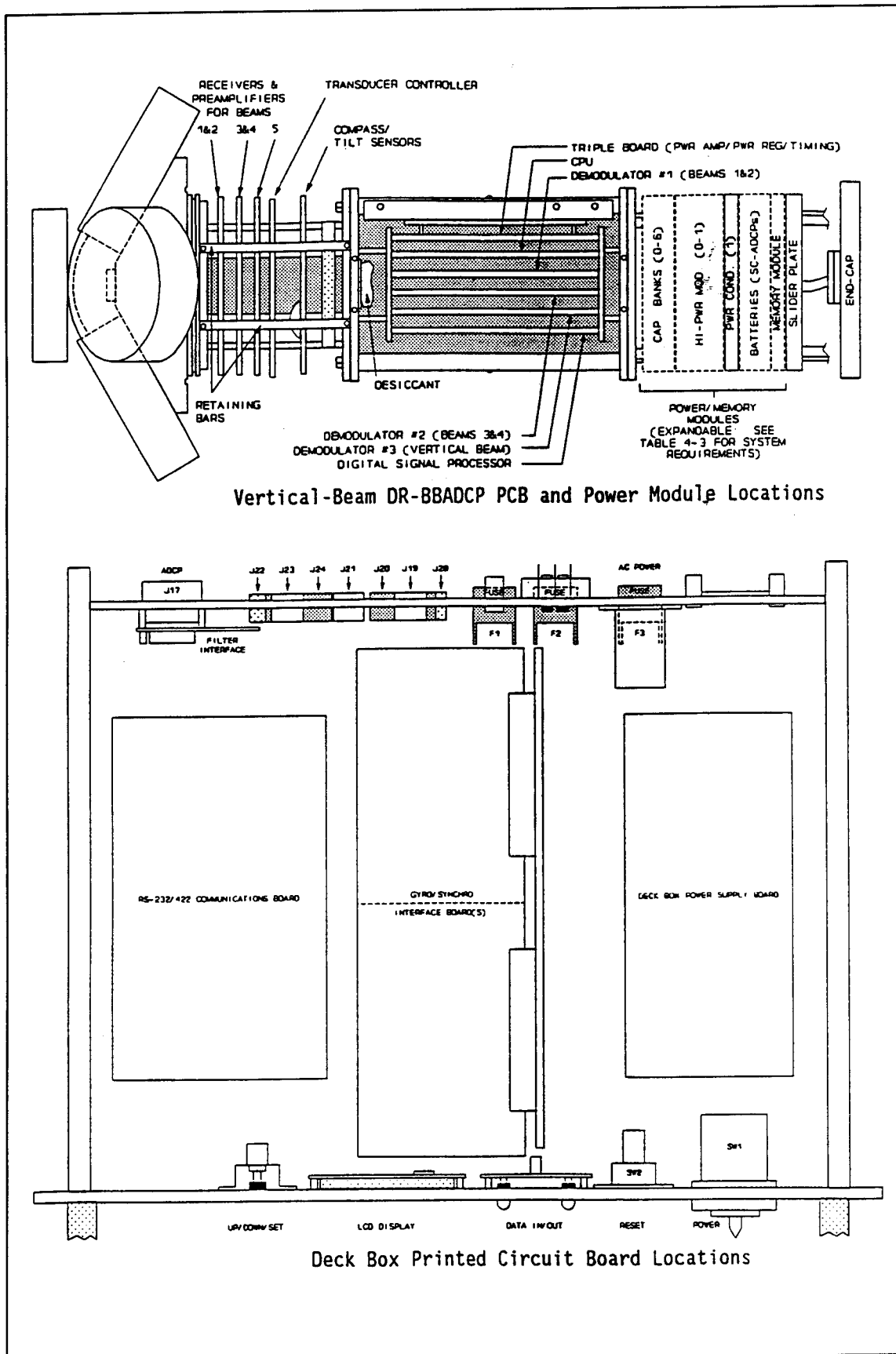
Air - 25.5 kg

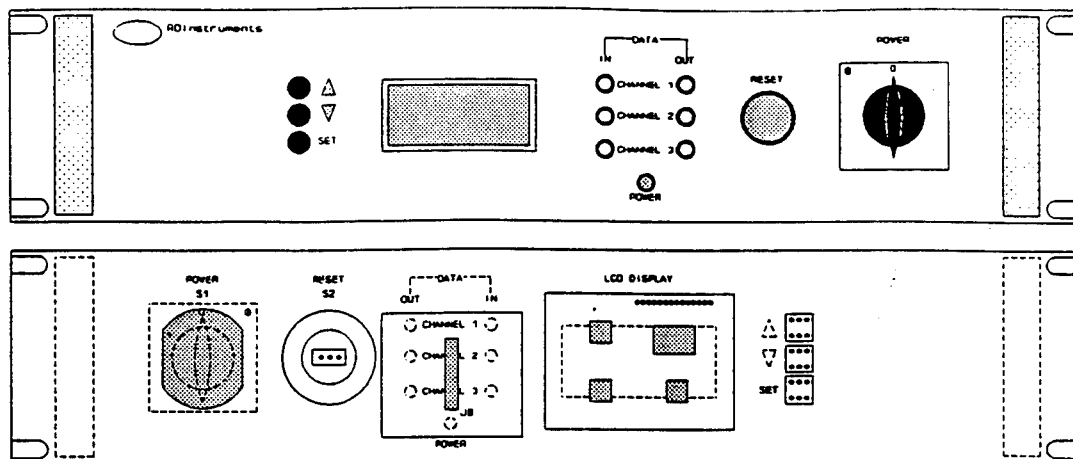
Water - 12 kg

Deep-water configuration

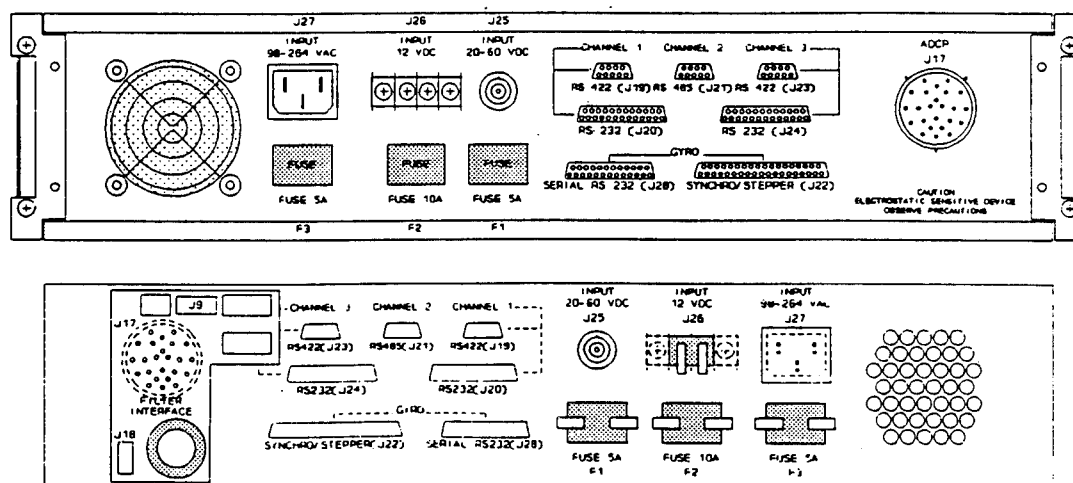
Air - 30.1 kg

Water - 10.8 kg





DR-BBDCP Deck Box Front Panel (Exterior and Interior View)



DR-BBDCP Deck Box Back Panel (Exterior and Interior View)

Appendix B

BBADCP Functional Description of PLUMES

This appendix presents a functional description of the broad-band acoustic Doppler current profiler (BBADCP) as it operates in PLUMES.

Overview of Operation

Refer to Figures B1 through B4. The following events occur during a collection cycle.

- a.* PLUMES Data Acquisition Software (DAS) sends a CS command to start the data collection cycle. The firmware program stored in the central processing unit (CPU) microprocessor takes control of the BBADCP operation based on the commands (see Chapter 4, "Firmware Setup Procedures") received through the serial I/O cable.
- b.* On the TRIPLE BOARD ASSEMBLY, the TIMING BOARD sends a transmit command to the POWER AMPLIFIER. This tells the BBADCP to start acoustic transmissions on the TRANSDUCERS.
- c.* The TRANSDUCERS receive echoes from the backscatter. The PREAMPLIFIERS and RECEIVERS amplify these signals and the DEMODULATOR BOARDS translate them to a base-band frequency and sample them.
- d.* The CPU module processes the received signals and sends them to the CPU to accumulate for averaging purposes.
- e.* The THERMISTOR measures water temperature at the transducer head and sends it to the CPU via the TRANSDUCER CONTROLLER.

- f.* The TRANSDUCER CONTROLLER sends pitch and roll from the TILT SENSORS and BBADCP heading from the COMPASS to the CPU.
- g.* The CPU repeats steps *b* through *g* for a user-defined number of pings. The CPU averages the data from each ping to produce an ensemble data set.
- h.* At the end of the ensemble (sampling) interval, the CPU sends the collected data to the serial I/O connector.

Functional Description of Operation

The following sections describe how the BBADCP operates and interacts with its modules. Refer to Figures B1 through B4 throughout these sections.

DC and Transmit Power Distribution

This section describes how the BBADCP processes the input direct current (DC) power to supply 5-volt V_{cc} to the electronics and how the BBADCP generates the high-frequency drive signal for the sonar transducers.

The BBADCP requires a DC supply between 20 and 60 volts. Power is applied over the sea cable to pins 15 (positive) and 16 (negative) on the external connector on the top end-cap. The power then goes through an electromagnetic interface (EMI) filter on a Printed Circuit Board (PCB) located in the end-cap. This filter reduces the chance that external noise sources associated with the deck-unit power supply and sea cable can disrupt BBADCP operation.

A Power Conditioner Module receives the filtered power. It then:

- a.* Limits the in-rush of current to the BBADCP and provides over- and negative-voltage protection. Either condition will blow a protective fuse.
- b.* Splits input power into operating power and transmitting power. The power conditioner module then sends both transmitter power and operating power to the triple board assembly. The triple board assembly receives both the filtered/isolated 20-60 VDC operating power and the transmitter power. This assembly consists of a power/timing main board and a power amplifier daughter board. The triple board assembly performs the following functions:
 - (1) Converts the operating power supply (filtered/isolated 20-60 VDC) in a DC-to-DC convertor to the +5 VDC (V_{cc}) used to power all other BBADCP circuits.

- (2) Uses the power/timing board to generate most of the timing and logic signals used by the BBADCP.
- (3) Uses the power amplifier board to generate the high-amplitude pulse AC signal that drives the sonar transducers. The power amplifier sends the drive signal to the tuning board.

Transducer Sensors

This section describes the standard BBADCP sensors for PLUMES. The transducer controller board controls the environmental sensors and contains unit-specific data. The sensors are:

- a. Temperature sensor (thermistor) - used to measure the water temperature. The system uses this data to calculate the speed of sound.
- b. Up/down sensor - determines whether the transducer head is facing up or down.
- c. Compass - determines the orientation of the BBADCP. Uses a floating, magnetic, flux-gate compass. Functional only when the BBADCP is within 20 deg from vertical.
- d. CTD interface - takes in conductivity, temperature, pressure, and OBS data from the external CTD.

An 8751 microprocessor controls a multiplexed analog-to-digital convertor to accept analog data from the sensors. Digital data are taken in directly. The transducer controller also generates the necessary signals based on CPU input to control the 4/5-beam switch on the tuning board and the gain control line for the receivers.

Calibration data for the sensors, a beam-angle correction matrix, and unit identification parameters (frequency, serial number firmware version, etc.) are stored in ROM. All necessary compensation is done before the sensor data are sent to the CPU. The interface to the CPU is via an RS-485 interface that has parallel lines to the memory board and to the output connector.

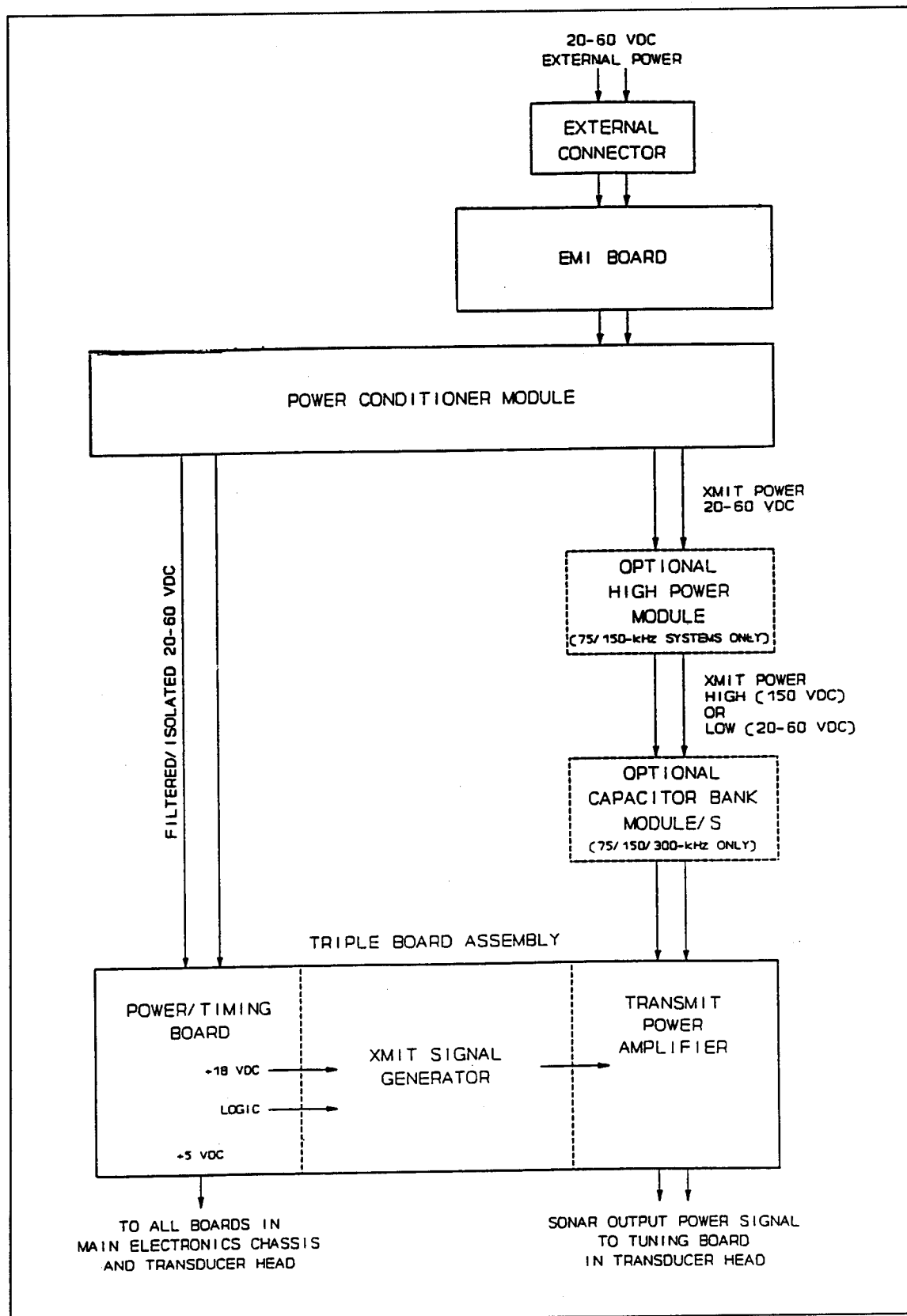


Figure B1. DR-BBADCPC DC and transmit power distribution block diagram

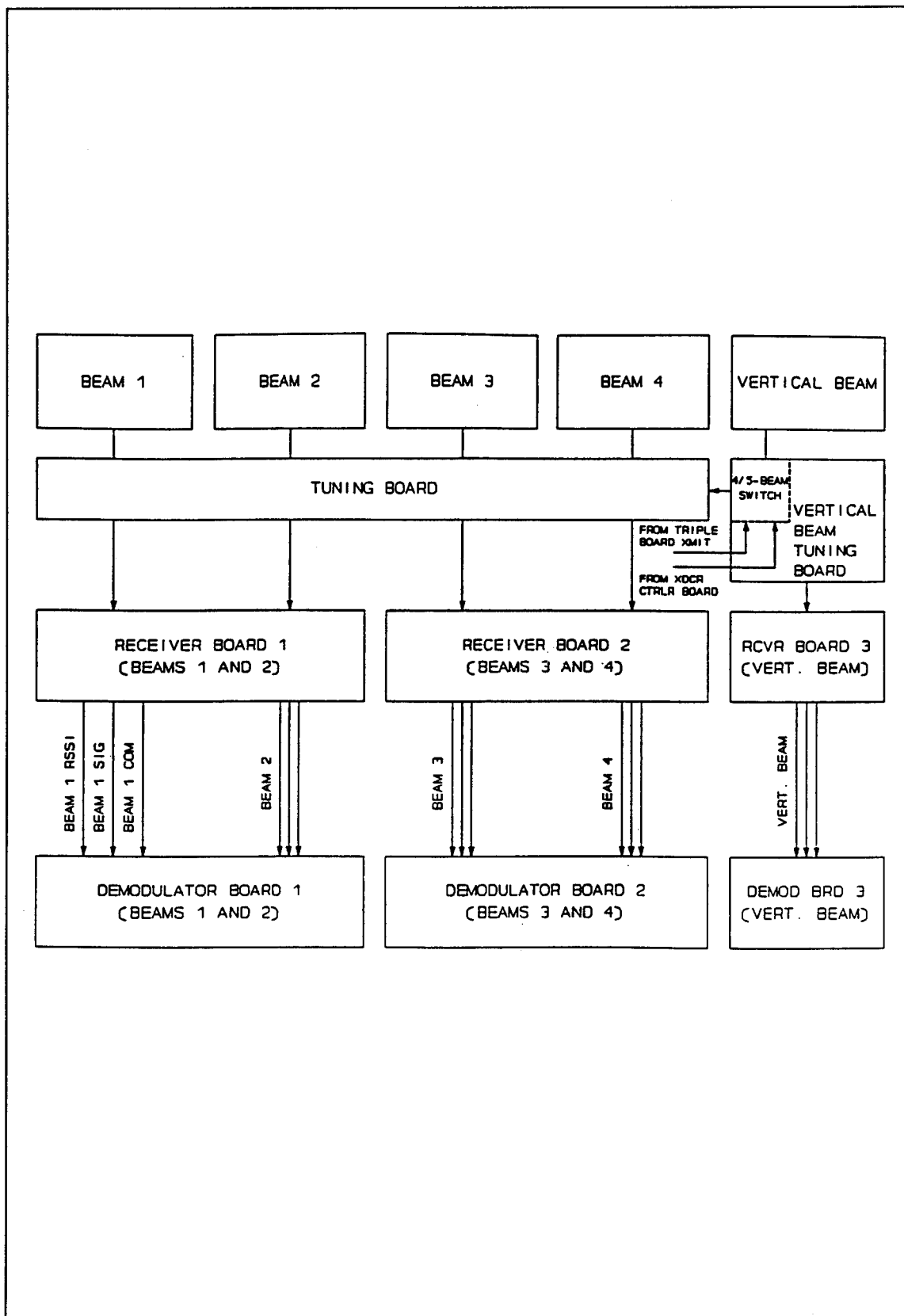


Figure B2. BBADCP transmit-receive path block diagram

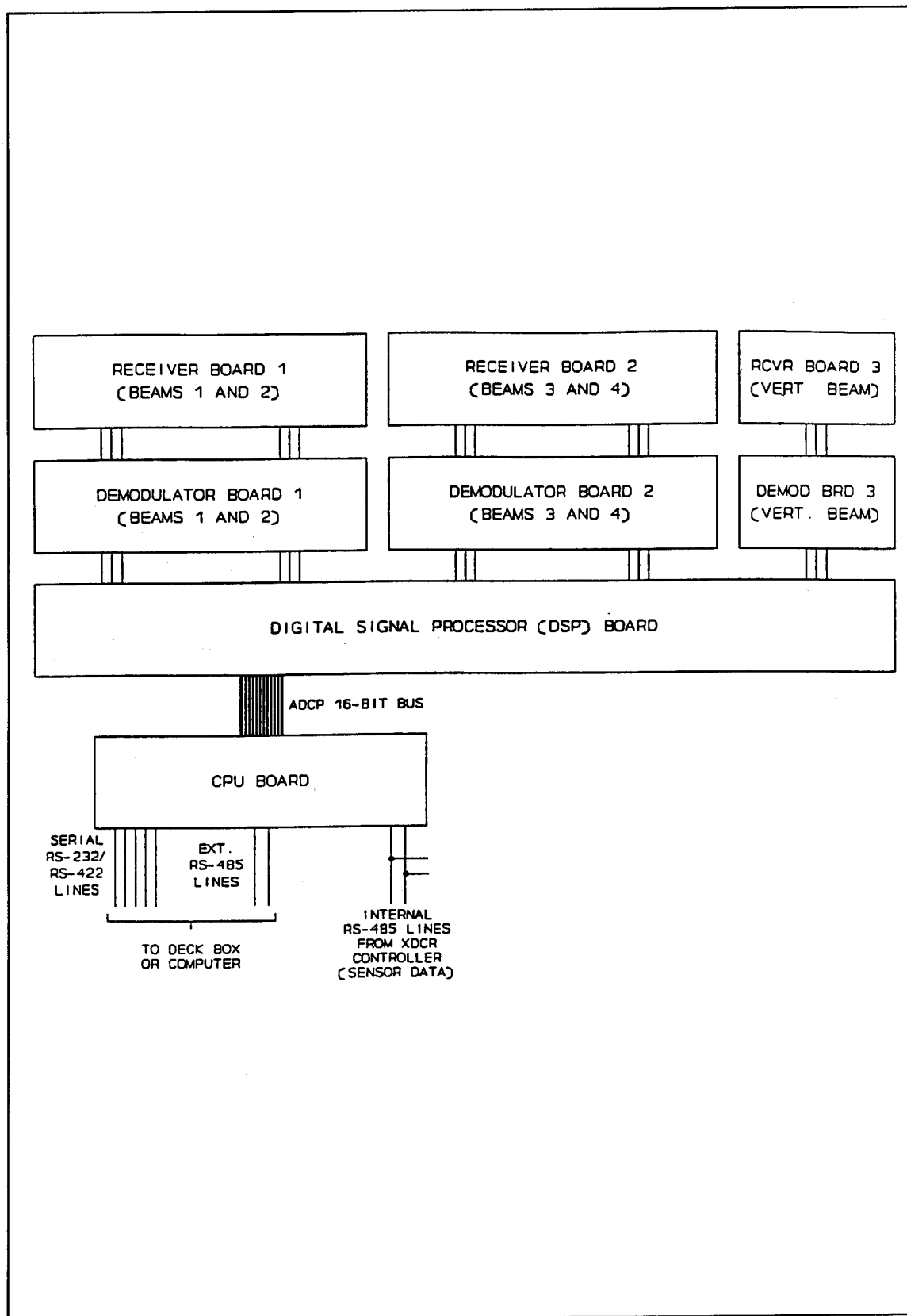


Figure B3. BBADCP electronics chassis block diagram

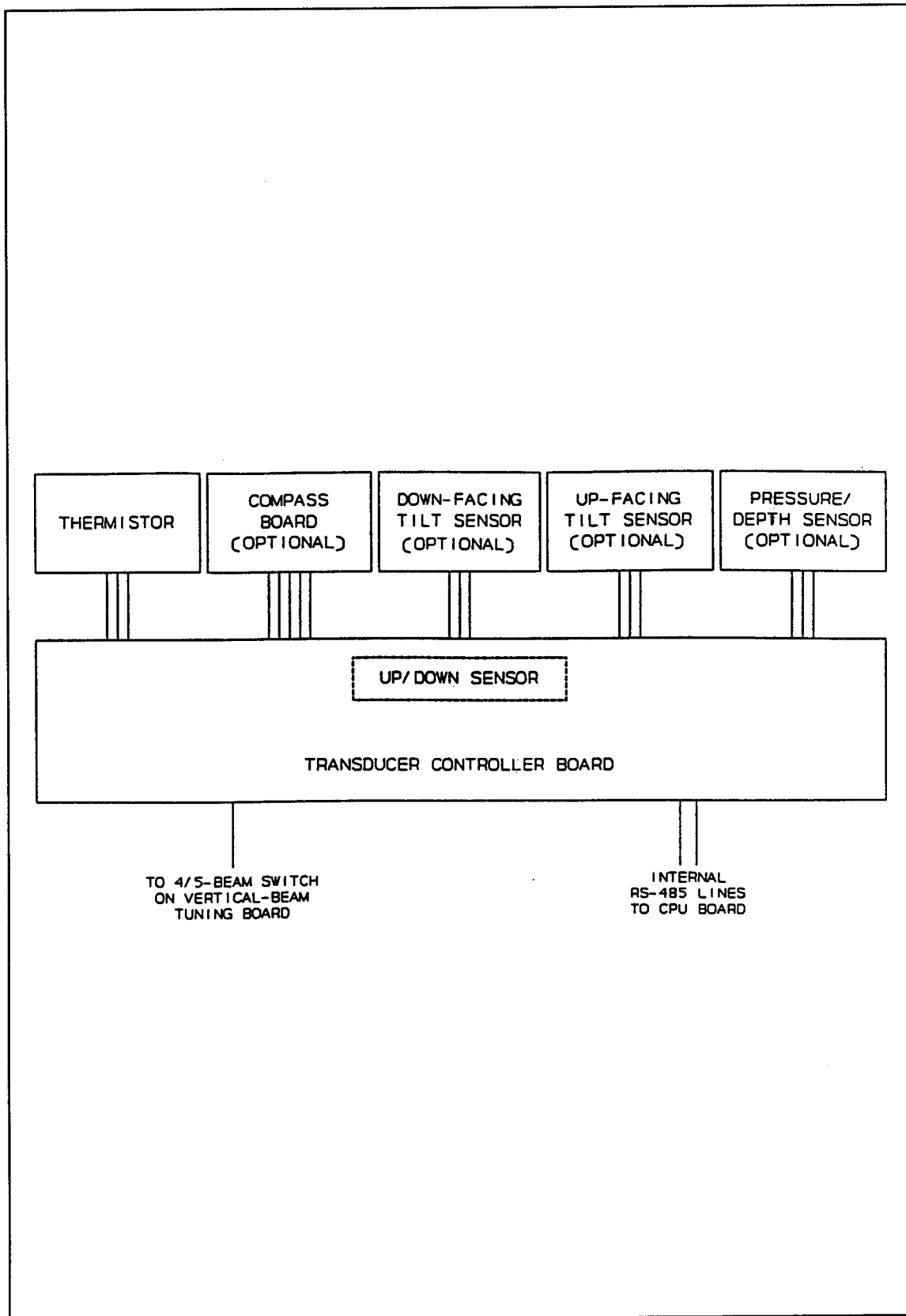


Figure B4. BBADCP transducer sensors block diagram

Appendix C

PLUMES Calibration and Ancillary Files

There are two calibration files that are input to the PLUMES data postprocessing software. These are the conductivity, temperature, and depth (CTD) calibration file and the broad-band acoustic Doppler current profiler (BBADCP) calibration files. All the postprocessing programs require the CTD calibration file when the system was configured for deep water, while the BBADCP calibration file is required only by CONCEN.

Examples of the CTD calibration reports for conductivity, temperature, and pressure sensor are included in this appendix. These reports include the formulas for converting conductivity and temperature frequency to degrees Celsius and millimho per centimeter, respectively, and for converting pressure voltage counts to pressure in pounds per square inch absolute. Pressure in pounds per square inch absolute is converted to gauge decibars by multiplying it by 0.6893 and subtracting approximately 9.8; this will leave some zero (i.e., on-deck) offset that can be taken care of in the setup menus of the postprocessing programs. A CTD calibration file is an ASCII file with the conductivity calibration coefficients on the first line, the temperature calibration coefficients on the second line, and the pressure calibration coefficients on the third line. Using the calibration reports in the appendix as examples, the CTD calibration file would be as follows:

```
2.10841972E-04 4.43662497E-01 -3.70033842E+00 3.24372766E-04 3.3
3.67323685E-03 5.82342330E-04 8.22584297E-06 -1.86942217E-06 2334.67
261.34567 -7.186206E-02 1.077659E-08
```

The five values determined by an acoustic calibration of PLUMES are stored in a BBADCP calibration file. They are used to calculate the source and reverberation levels (see the "Transmitted Signal" and "Received Signal" sections in Chapter 2). They are the only values stored in the file. The BBADCP calibration file is an ASCII file with a single line consisting of the four calibration values (i.e., CAL_1, Cal_2, Cal_3, Cal_4, Cal_5). An example would be as follows:

180.5 0.11 69.7 0.169 0.406

The grain-size distribution file is an ASCII file consisting of the size classes (particle diameters), in microns, and the percentages by weight of sediment having a diameter greater than its corresponding size class, but less than the next class. The values are entered by the user with one class per line. The first entry in the file is the number of classes used to represent the distribution. This is followed by class sizes, and the corresponding percentages, one for each line in the file. An example is shown below.

```
nnn
ddd. pp.pp
ddd. pp.pp
ddd. pp.pp
....
....
```

nnn is the number of classes used to represent the distribution.
ddd. are the class particle diameters in microns.
pp.pp are the percentages by mass of the sediment in the classes. The number 00.00 must be entered when none of the sediment is in a classification.
The total for all classes must be 100.00.

The backscatter intensity background files consist of an ADCP count for each intensity bin. The files are ASCII files, <CR><LF> delimited, having the following format:

```
bbb
bbb
bbb
bbb
...
...
```

bbb are the corrected ADC backscatter intensity counts in the files for corrected data and uncorrected backscatter intensities for the uncorrected data files, one for each fifth beam intensity bin.

SEA - BIRD ELECTRONICS, INC.
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CONDUCTIVITY CALIBRATION DATA
CALIBRATION DATE: 23-Jul-93

PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

SENSOR SERIAL NUMBER = 438

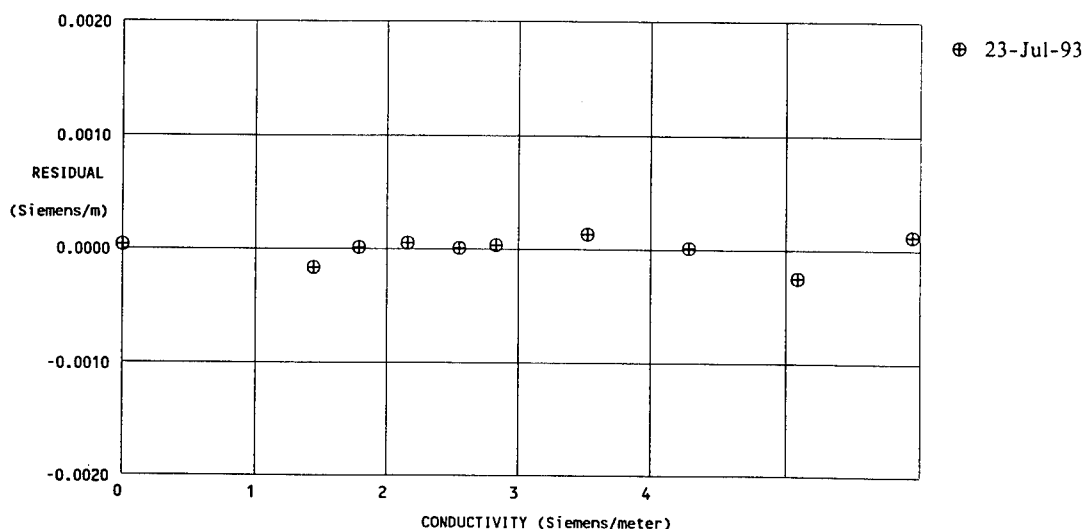
a = 2.10841972e-04 b = 4.43662497e-01
c = -3.70033842e+00 d = 3.24372766e-04
m = 3.3

BATH TEMP (°C)	BATH SAL (°/oo)	BATH COND (Siemens/m)	INST FREQ (kHz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
31.0398	34.9502	5.93882	11.85400	5.93894	0.00012
22.9584	34.9516	5.08814	11.03141	5.08789	-0.00025
14.9569	34.9531	4.28203	10.19001	4.28204	0.00001
6.9317	34.9535	3.51779	9.32075	3.51792	0.00013
-0.9103	34.9531	2.82222	8.45043	2.82226	0.00004
27.0183	14.8081	2.53927	8.06773	2.53928	0.00001
18.9930	14.8078	2.15220	7.51454	2.15225	0.00005
11.0185	14.8078	1.78659	6.95099	1.78660	0.00001
3.0070	14.8080	1.44224	6.37398	1.44208	-0.00016
0.0000	0.0000	0.00000	2.88540	0.00003	0.00003

Conductivity = $(af^m + bf^2 + c + dt) / [10(1 - 9.57(10^{-8})p)]$ Siemens/meter, where p = pressure in dbars

Residual = instrument conductivity - bath conductivity

NOTE: Multiply Siemens/meter by 10 to obtain mmho/cm



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TEMPERATURE CALIBRATION DATA
CALIBRATION DATE: 23-Jul-93

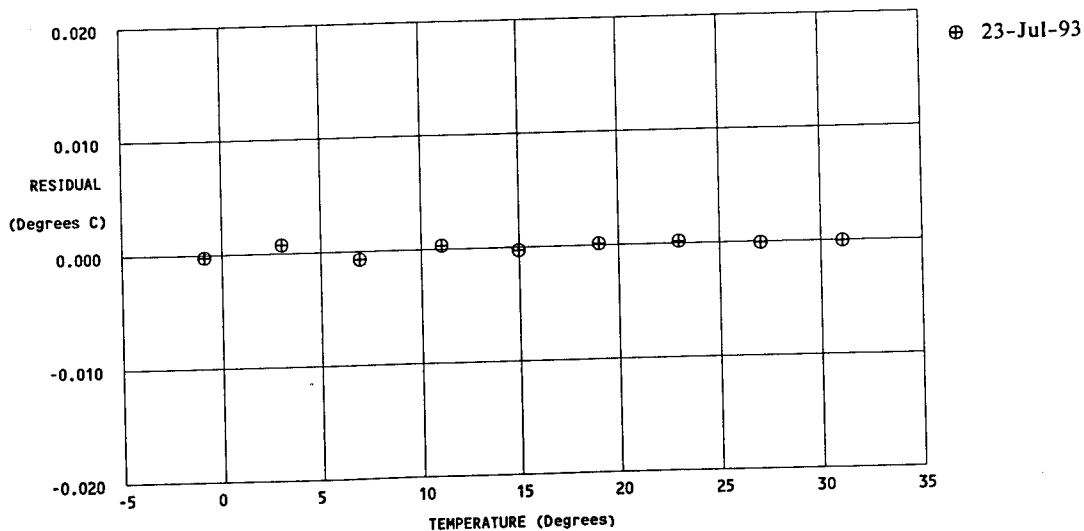
SENSOR SERIAL NUMBER = 438

a = 3.67323685e-03 b = 5.82342330e-04
c = 8.22584297e-06 d = -1.86942217e-06
f₀ = 2334.67

BATH TEMP (°C)	INSTRUMENT FREQ (Hz)	INST TEMP (°C)	RESIDUAL (°C)
31.0398	4561.70	31.0398	-0.00002
22.9584	3898.04	22.9586	0.00019
14.9569	3310.57	14.9566	-0.00028
6.9317	2786.90	6.9310	-0.00072
-0.9103	2334.67	-0.9105	-0.00024
27.0183	4222.34	27.0182	-0.00009
18.9930	3598.50	18.9931	0.00011
11.0185	3045.68	11.0188	0.00030
3.0070	2553.55	3.0078	0.00075

$$\text{Temperature} = 1/[a + b[\ln(f_0/f)] + c[\ln^2(f_0/f)] + d[\ln^3(f_0/f)]] - 273.15 \text{ (°C)}$$

Residual = instrument temperature - bath temperature





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SBE 193405-438

28 July 1993

Pressure calibration: Senso-Metrics SP91FFS 500 psia S/N 9F062

Straight Line Fit:

Pressure(psia) = $M * N + B$ (N = Binary output)

M = -0.07186 B = 261.40

Quadratic Fit:

Pressure(psia) = $A0 + A1 * N + A2 * N * N$ (N = binary output)

A0 = 261.34567 A1 = -7.186206e-02 A2 = 1.077659e-08

Pressure (psi)	Output (N)	Straight Line Fit		Quadratic Fit	
		error, psi	error, %FS	error, psi	error, %FS
14.59	<u>3433.98</u>	0.046	0.01	0.110	0.02
100.06	<u>2246.19</u>	-0.068	-0.01	-0.076	-0.02
200.12	<u>854.05</u>	-0.088	-0.02	-0.140	-0.03
300.18	<u>-542.01</u>	0.173	0.03	0.119	0.02
400.24	<u>-1932.99</u>	0.070	0.01	0.055	0.01
500.30	<u>-3322.68</u>	-0.126	-0.03	-0.061	-0.01
400.24	<u>-1933.14</u>	0.081	0.02	0.065	0.01
300.18	<u>-542.23</u>	0.189	0.04	0.135	0.03
200.12	<u>853.74</u>	-0.066	-0.01	-0.118	-0.02
100.06	<u>2246.00</u>	-0.055	-0.01	-0.062	-0.01
14.59	<u>3435.03</u>	-0.029	-0.01	0.035	0.01

Output binary values are averages of 101 samples taken at 2 Hz.

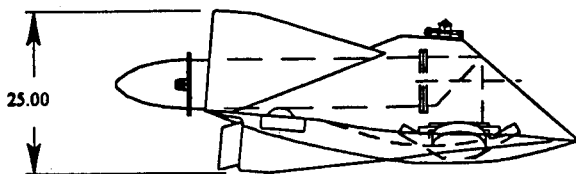
SEASOFT Versions 3.3M and higher will prompt for A0, A1, and A2

SEASOFT Versions 3.3L and lower will prompt for M and B

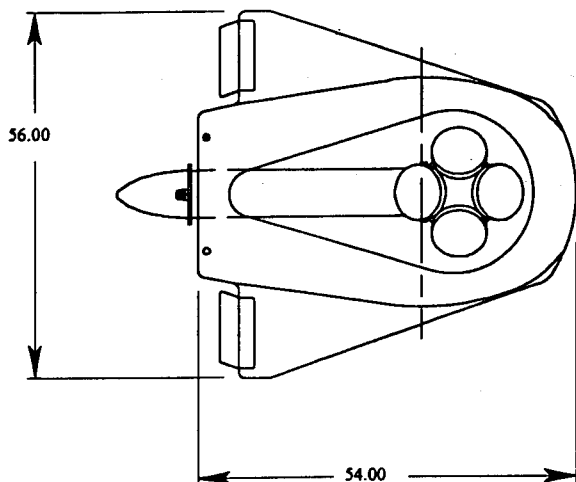
Appendix D

Towed Vehicle Specifications

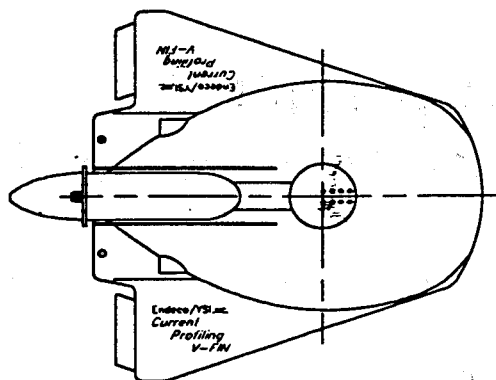
This appendix gives the specifications from the manufacturer, Endeco/YSI Inc., for the towed vehicle.



SIDE VIEW



BOTTOM VIEW
(WITH WITH 150 kHz DR ADCP)



TOP VIEW

THE CPV- Fin IS DESIGNED TO ACCEPT THE
RD INSTRUMENTS ADCP FROM 150 - 1200 kHz.
THE ADCP MUST BE EQUIPPED WITH THE 90°
ADAPTER.

SPECIFICATIONS:

MATERIALS:

BODY- REINFORCED FIBERGLASS WITH 6061-T6 ALUMINUM BACKING PLATES
TOW FITTING- STAINLESS STEEL
TRIM TABS- STAINLESS STEEL
TAILS- ANODIZED ALUMINUM
ADCP MOUNTING BRACKETS- STAINLESS STEEL

WEIGHT:

IN AIR- 265 LBS.
IN WATER- 175 LBS.

STABILITY:

ROLL- $\pm 2^\circ$
PITCH- $\pm 3^\circ$ (@ 10 KNOTS)

TOWING SPEED:

MAX. 12 KNOTS

TOWING DEPTH:

DEPENDS ON VESSEL SPEED, CABLE SPECIFICATIONS AND PRESSURE LIMIT
OF ADCP HOUSING (COMPUTER ANALYSIS OF CABLE TOWING PROFILE IS AVAILABLE).

DEPRESSIVE FORCE:

@ 5 KNOTS- 450 LBS.
@ 10 KNOTS- 1250 LBS.
@ 12 KNOTS - 1850 LBS

All dimensions shown are in inches.

Appendix E

BBADCP Commands for PLUMES

This appendix describes the broad-band acoustic Doppler current profiler (BBADCP) firmware commands that are unique to PLUMES. A description of all commands can be found in Appendix C in the RDI Manual.

KE - CTD enable

Purpose	: Turns on/off conductivity, temperature, and depth (CTD) optical backscatter sensor (OBS) data collection.
Format	: <i>KEn</i>
Range	: $n = 0$ (off), 1 (on).
Description	: KE controls CTD/OBS data collection. KE0 turns data collection off. KE1 turns on sampling requests to the CTD and instructs the BBADCP to include CTD/OBS data in the output ensemble record.

KI - CTD time between samples

Purpose	: Sets the interval between CTD data collection cycles.
Format	: <i>KIhhmmssff</i>
Range	: $hh = 00$ to 23 hr. $mm = 00$ to 59 min. $ss = 00$ to 59 sec. $ff = 00$ to 99 hundredths of seconds.
Description	: KI sets the interval between the start of the CTD sampling period (about 15 sec long) and the start of the data transmission over the RS-485 interface.
Note	: It is recommended that for PLUMES, the default value of 15 sec not be changed.

KN - Navigation data availability

Purpose : Turns on/off navigation data buffer.
Format : KN*n*
Range : *n* = 0 (off), 1(on).
Description : KN controls the 20-byte data buffer within the output data ensemble used by DAS for navigation data. KN0 disables the data buffer. KN1 enables the data buffer and fills it with zeroes.

VD - Fifth-beam data out

Purpose : Selects the fifth-beam data collected by the BBADCP.
Format : VD*nnn nnn nnn*
Range : Firmware switches (see “description”).
Description : VD uses firmware switches to tell the BBADCP the type of fifth-beam data to collect. For PLUMES, this is BBADCP echo intensity, and the default setting is:

VDxx1 xxx xxx = collect fifth-beam backscatter intensity.

VF - Fifth-beam blank after transmit

Purpose : Moves the location of the first depth cell away from the fifth-beam transducer face to allow the transmit circuits time to recover before the receive cycle begins.
Format : VF*nnnn*
Range : *nnnn* = 0-9999 cm
Description : VF positions the center of the first depth cell at a vertical distance (2 x VF) from the vertical transducer face.
Note : To align fifth-beam depth cells with velocity depth cells using WM4, set VF to:

$$VF = WF + 1/2(WS - VS) + 1/2 \text{ the minimum of } (WS \text{ or } WS_{\text{default}})$$

where

WS_{default} is the default value of WS (see Table C-2 in the RDI manual).

VM - Fifth-beam profiling mode

Purpose : Selects the application-dependent profiling mode used by the fifth beam.
Format : VM*n*

Range : $n = 1$
 Description : VM1 uses a transmit pulse matched as closely as possible to the depth cell size (VS-command).
 Note : At present, fifth beam systems only use Mode 1.

VN - Fifth-beam number of depth cells

Purpose : Sets the number of depth cells over which the fifth beam collects data.
 Format : VNnnn
 Range : nnn = 001 to 128 depth cells.
 Description : The range of the fifth beam is set by the number of depth cells (VN) times the size of each depth cell (VS).

VP - Fifth-beam pings per ensemble

Purpose : Sets the number of pings to average in each data ensemble for the fifth beam.
 Format : VPnnnnn
 Range : nnnnn = 0 to 16,384 pings.
 Description : VP sets the number of fifth-beam pings to average in each ensemble before sending the fifth-beam data.
 Note : If (BP>0) or (WP>0), the BBADCP interleaves fifth-beam, bottom-track, and velocity pings and spreads them as uniformly as possible throughout the ensemble period. If (BP = WP = VP), the ping-cycle order is bottom ping, velocity ping, then fifth-beam ping.

VS - Fifth-beam depth cell size

Purpose : Selects the cell size (vertical thickness) for fifth-beam measurements.
 Format : VSnnnn
 Range : nnnn = 0 to 9999 cm.
 Description : The BBADCP collects data over a variable number of fifth-beam depth cells. VS sets the size of each cell in vertical centimeters.

Appendix F

Navigation Data Input Format for DAS

The data from the navigation device to DAS must follow the NMEA 0183 standard. Each data “sentence” should have the following format for a DGPS:

`$--aaa,hhmmss.ss,b,ccdd.dd,n,ffgg.gg,e,,,xyyyz, i.i,1*kk<CR><LF>`

`$--aaa` is the NMEA “Talker ID” (`$--`) and field description (`aaa`), the field description is not decoded by DAS and can be any characters.

`hhmmss.ss` is two fixed digits of hours, two fixed digits of minutes, two fixed digits of seconds, and an unspecified number of digits of decimal fraction of seconds.

`b` is the status character (i.e., A for valid data, V for invalid data).

`ccdd.dd` is two fixed digits of degrees of latitude, two fixed digits of minutes of latitude, and an unspecified number of digits of decimal fraction of minutes of latitude.

`n` is the hemisphere identifier character (i.e., N for north latitude and S for south latitude).

`ffgg.gg` is three fixed degrees of longitude, two fixed digits of minutes of longitude, and (specifically for DAS) two fixed digits of decimal fraction of minutes of longitude.

`e` is the east/west identifier character (i.e., E for east longitude and W for west longitude).

`,,` are two null fields

`xx` is the day

`yy` is the month

zz is the year

i.i is the magnetic variation in an unspecified number of digits of degrees and fraction of degrees.

l is the direction of variation character (i.e., E for east variation and W for west variation).

kk is the checksum and is the ASCII representation of the 8-bit exclusive OR (no start or stop bits) of all characters in the sentence, including " ' " delimiters between, but not including, the " \$ " and the " * " delimiters.

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